THE UNIVERSITY OF ALBERTA

THE ECOLOGICAL IMPLICATIONS OF TRAIL USE, CYPRESS HILLS, ALBERTA

by

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A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

DEPARTMENT OF GEOGRAPHY

EDMONTON, ALBERTA

FALL, 1972

UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled THE ECOLOGICAL IMPLICATIONS OF TRAIL USE, CYPRESS HILLS, ALBERTA, submitted by Janice Elizabeth Peters in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

The subject of this study is the impact of man's recreational activities on the natural environment. A detailed soils and vegetation study was conducted on footpaths, which because of their linear form, provide an opportunity to contrast a trodden area with undisturbed areas over a short distance. The applicability of established methods to such a study is discussed, and alternatives are considered.

The study showed that measurable differences in soil characteristics occur across a trail. Bulk density and pH decreased with distance from the centre of the trail, while organic carbon content, water content, and air-filled pore space increased. A distinctive pattern in plant species cover and distribution was also found. Associated with the edge of the trail are six edge species with characteristics that enable them to tolerate the unfavourable conditions.

A model of the development of a trail over time which incorporates the results of this study is presented. A discussion is included of other variables which are thought to be influential. A final consideration is given to future research methods, and the necessity of integrated studies is stressed.

ACKNOWLEDGEMENTS

My thanks go to my supervisor, Dr. D. Gill, and to Dr. J. Mayo I would like to extend my especial thanks for his interest.

I am grateful to those who provided me with laboratory space and equipment, particularly Dr. Nyborg and Dr. Pettapiece of this university, and those of the Botany Department at U.C.L.

For permission to work in the Cypress Hills Provincial Park I have to thank Mr. Drinkwater, and for assistance with information while in the field area I would like to thank Mr. A. Salus. For very different reasons I would also like to thank Gerry and the ecology crew.

My thanks also go to my fellow grad students for their moral support and to Irene and Kathy who did the typing. To Penny I would like to express my especial thanks for her help and encouragement. Finally, I would like to thank David, to whom I am indebted for his help and support from the beginning to the end of this project.

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CHAPTER I

INTRODUCTION - A REVIEW OF RECREATION IN AN ECOLOGICAL CONTEXT

1.1 Leisure and Recreation

The problem of filling many potentially boring leisure hours was a real one to many a genteel Victorian and non-existent to the working classes. The passing of two world wars and an economic depression has brought a period today in which leisure is valued far more highly, and certainly has a more equitable distribution. As with other privileges once considered the prerogatives of the wealthy, a more meritocratic social climate coupled with the rise of the middle classes in western industrial countries has ensured that a considerable amount of leisure time has become available to a majority of the population. Increasing urbanisation accounts in part for the massive exploitation of this leisure time in the countryside, facilitated by the increasing mobility of the populace. Countryside recreation has moved into the realm of big business, and must compete with the other contenders for more rural land: urban and rural development, agriculture, forestry for both timber and water storage and supply purposes, and mineral exploitation. Concurrent with the increasing demand for recreation land however, there is also an increasing concern for the quality of the countryside (Hookway and Davidson, 1970).

Two basic terms, leisure and recreation, should be defined before continuing further. Both suffer from being used frequently and often without being clarified. The Countryside Recreation Research Advisory Group (CRRAG) has endeavoured to remedy the lack of standard definitions

in the recreation field by preparing a glossary of terms (CRRAG, 1970), from which the following are taken:

> "Leisure is the time available to an individual when the disciplines of work, sleep, and other basic needs have been met."

> "Recreation consists of any pursuit engaged upon during leisure time, other than those to which people are normally 'highly committed'."

Highly committed activities include for example child care, religion, house repairs and car maintenance. Recreation pursuits are divided into active and passive, depending on the amount of physical exercise involved. Active pursuits would include water and winter sports, riding and football; passive pursuits include pleasure motoring, sunbathing and sightseeing.

It is not surprising that the rapid expansion of the recreation industry has placed a certain amount of stress on natural areas. The resulting strain as the environment adjusts to this new situation is manifested in many forms of site deterioration. There is a need to determine the level of use which can be tolerated by different environments for a variety of activities, and combinations of activities, with an acceptable level of induced deterioration. The use to which an area should be put for recreational purposes should be determined by its individual potential for the desired activities relative to those of nearby areas and in conjunction with user requirements and characteristics. It should be the duty of government, having the necessary legislative powers and acting in the interests of the country, to ensure that the natural resources of an area developed for recreation are made available to the populace and maintained in an adequate condition.

1.2 Social Implications of Recreation Planning

Much of the current literature on leisure and recreation is concerned with issues more pertinent to the social sciences than to environmental sciences. The main areas of research will be discussed briefly however, as there is often a lack of awareness between disciplines which would have much to offer one another. One must accept that scientific research of this nature is not carried out in vacuo, but that the outcome of such studies may also have social consequences as well as the more obvious scientific ones. An example to clarify this might be the physically and biologically determined level of use which a particular site can tolerate. If this necessitates restrictions on visitor use, it is useful to know the patterns of such use, whether visitation is light or intensive, frequent or limited to a few occasions, and the characteristics of the visitors: why they have travelled to this place and the distance they have come, and the age groupings of families. Decisions must be made in the knowledge of how, and whom they will affect. Although policy decisions are the outcome of value judgements on what should be scientifically conducted studies and recommendations, the physical scientist should nevertheless be aware of the broader issues arising from his work .

The sociologist may also offer insights to the recreation planner on the role of leisure in society (Roberts, 1971). Understanding the motivation to pursue various recreational activities is of value, not only when the recreational needs can be fulfilled, but also when an acceptable substitute for the preferred activity or location is required. Also from a sociologist comes a warning about mechanisms designed to limit recreation activities, in particular the 'social filter' (Emmett, 1971). In its most evident form this is seen in the exclusive

golf club, but, she suggests, it also occurs through controls exercised by the British Forestry Commission and National Trust, private landlords, farmers, and so on, in the form of paternalism and the idea of exclusiveness - a perpetuation of use by a particular kind of people. This concept may be less applicable to North America than it is to Europe with its more defined class system, or it may be that in North America it operates on a different set of criteria. A similar cautionary note was sounded by Wibberley (1971), in pointing out that decisions in countryside planning are increasingly influenced by powerful interest groups.

1.3 Tools for Recreation Planning

1.3.1 Visitor-use Surveys

A great deal of work has been done on aspects of visitor use, especially in Canada and often by means of a questionnaire. Examples are the visitor-use surveys of Thorsell (1966; 1968) in Waterton Lakes National Park and Banff and Yoho National Parks. Analysis of the questionnaire responses characterises the visitors and their activities and helps to point out any relationships which may be found between for example, distance travelled and length of stay, or the seasonal variation in trip patterns (Wall, 1971). Surveys however can only characterise the visitation at a particular moment in time, and must be repeated if it is wished to monitor the changes that occur over time and in response to management techniques.

1.3.2 Recreation Demand Analysis

Attempts have been made based on theory and recreation studies to build models that describe and predict the various facets of recreation demand. Before pursuing this however, additional definitions are necessary. Recreation demand is defined as the number of persons (or

participatory units) requiring to take part in a particular recreation facility, and is seen as a demand for facilities (Law, 1970). This existing demand is composed of several parts: effective demand which is the present participation, latent demand comprising deferred demand (those with the means and time to participate but unable to do so because of a lack of facilities or knowledge of them) and potential demand (those who wish to participate but lack the means or time, or both) and finally there is the element of no-demand - those too old, sick or otherwise unable or uninterested in participating.

Demand studies are therefore concerned with predicting the future recreation requirements in terms of effective demand for them. This contrasts with visitor surveys (which may be used in demand studies) the main objectives of which are to study present effectiveness or use of resources. Clawson and Knetsch (1966) have contributed to demand analysis by developing demand curves, as have Burton and Noad (1968), who are also orientated to this type of recreation research. Cesario (1969) suggested the use of operations research tools in recreation planning by locating facilities in accordance with the travel flows to recreation sites in the system. Detailed models have been produced for selected aspects of recreation, for example leisure motoring (Hall, 1971).

1.3.3 Ecological Surveys

The needs of visitors and the effect of the environment upon them are evidently important aspects of recreation planning. It is however a mutually interacting situation, and the impact of visitors upon the environment must also be considered. It is clear that the environment can only support a certain amount of pressure and will deteriorate if over-used. One might hypothesise that a feedback mechanism would

operate, such that sufficient deterioration of a site would lessen its attraction to visitors, reduce visitation and hence lighten the pressures on that site. Natural revegetation might then occur. Unfortunately there is little evidence that such an inbuilt control exists and indeed the modern visitor from the urban habitat often seems to positively seek the close proximity of his fellows, even when offered the opportunity to be apart from them. It is inevitable then that intensive use will produce adverse effects on even the most resistant environment; the management goal of minimising these effects must be based on the ecological principles that govern them. Ecological surveys should therefore have a high priority and may be used in setting limits upon the use an area can receive, based on its carrying capacity. This concept is discussed in the next section.

1.4 Recreation Carrying Capacity

Turning from user-oriented and demand studies, it has been shown that recreation planning and management must be based on the capacity of an area to support different kinds of recreational activity. This calls to mind the ecological concept of carrying capacity, defined as the upper limit or equilibrium level of a population when its growth follows a sigmoid form (positive acceleration phase, logarithmic phase, negative acceleration phase) (Odum, 1959). This has been interpreted in a definition of recreation carrying capacity (CRRAG, 1970) as "the level of recreation use that an area can sustain without an unacceptable degree of deterioration of the character and quality of the resource or of the recreation experience." Four different sub-types of capacity are recognised by CRRAG:

i. Physical capacity. This is the maximum level of recreation use, in user-units (people, cars, boats, etc.) for which a particular

facility was designed.

ii. Ecological capacity. The maximum level of recreation use in terms of numbers and activities that can be accommodated before a decline occurs in ecological value, assessed from the ecological viewpoint.

iii. Economic capacity. The maximum level of recreation use which can be accommodated in an area that is also used for some non-recreational purpose before damage becomes economically unacceptable from a management viewpoint. An example is boating on a reservoir which is also used as a water supply.

iv. Perceptual capacity. The maximum level of recreation use above which there is a decline in the recreation experience of the recreation participant, varying according to individuals and the recreation activity considered.

It can be seen that definition of recreation carrying capacity is open to interpretation of what is an 'unacceptable degree' of deterioration of the 'character' and 'quality' of the resource or recreation experience. This serves to highlight some of the management and planning problems, for even if the degree of deterioration can be assessed, it must still be decided whether that degree is acceptable or unacceptable. It is interesting to note that this definition implies a value judgement (...an unacceptable degree...). This is in contrast to Wagar's (1964) definition of recreation carrying capacity as the level of recreation use an area can withstand while providing a "sustained quality of recreation", that is, the level of use at which quality remains constant. No qualification is attached to quality, which may therefore be at any level, and certainly would be at a low

level on a heavily over-used site. Wagar's definition then is more closely related to the ecological definition (Odum, 1959) in implying equilibrium conditions at which both population and environment have a certain stability. 'Quality' is used in both these definitions purely as a descriptive term and without the implication of attached value as is seen in the often used phrase 'a quality recreation/wilderness experience'.

The definition of ecological capacity similarly invites a broad interpretation of the 'decline in ecological value' especially as it is to be assessed from the ecological viewpoint and presumably by ecologists. Perhaps it is best viewed in the light that ecology is the study of the interaction of biotic and abiotic systems; that ecosystems develop from a young stage characterised by high net production and rapid growth to a mature stage of low net production, stability and diversity. In other words, the overall strategy of ecosystem development is directed to achieving the largest and most diverse organic structure possible, given the limitations of the available energy input and physical conditions of existence (Odum, 1969). The net result of internal community action is symbiosis, nutrient conservation, stability and a decrease in entropy. For the purpose of this argument we are most concerned with the stability of the system, the resistance it offers to external perturbations. The mature ecosystem has more refined homeostatic mechanisms to dampen the effects of disturbance than does the less mature ecosystem. However, we are not inflicting minor pressures on the environment in many cases, nor are we dealing with a closed system. There is a tendency therefore for the system to revert to a younger, or earlier, successional stage instead of absorbing the disturbance while remaining in a mature stage. In addition we have not given ecosystems the necessary time to adapt to

our pressures; as Odum (1969) points out, most of the stresses introduced by man are too sudden, violent or arrhythmic for adaptation at the ecosystem level and so tend to give rise to severe oscillation instead. The hypothesis of Darling and Eichhorn (1967) is that, given time, there will be an adjustment to counteract recreational pressures.

Perhaps 'a decline in ecological value' may now be interpreted in terms of the effect of pressures on the progress of succession and the characteristics of the different stages of succession. This may not be the whole answer; if it were so we would have to accept that such practices as using fire to maintain pyrogenetic communities such as pine forests represents a decline in ecological value. This may very well be so, but it maybe at the present economically more desirable than allowing succession to follow its course. 'Economically more desirable' is a term which reflects the current social-economic climate, which seems likely to undergo some drastic changes in the near future if we are to pass from this 'bloom' stage of population growth to a more stable, protection-oriented stage of equilibrium density.

For the present then, it may be possible to measure a decline in ecological value by the amount of change a system has undergone in being diverted by man from its current successional status. An interesting aspect of this is that it is still not known whether mature ecosystems continue to age, so that the period of maturity and stability is followed by a senescent phase when the ecosystem is again more susceptible to change. A final point is that implicit in the term 'ecological value' is really the value to man - to a person, group or agency - and here again the filter mentioned previously (Emmett, 1971) is likely to operate.

1.5 Ecological Impact of Recreation - A Literature Review

1.5.1 General Ecological Impact of Recreation

Given that adverse effects on the environment will occur where there is mis-use or over-use, it is then pertinent to enquire what form these will take. As examples of the degradation in habitat quality in Britain,Phillips (1970) cited the limited variety of flora on Box Hill, Surrey and bird life on the Broads in areas used intensively for boating. Dune systems and "inland wetlands" are two of the most fragile ecosystems for recreation use (Hookway and Davidson, 1970) and pollution, trampling, litter and fire are the main causes of site degradation. In 1967 the International Union for Conservation of Nature and Natural Resources (IUCN) published the proceedings of a conference devoted to the impact of recreation on the environment. Perhaps due in part to the shortness of the papers, one gains from the proceedings an impression of superficial generalities, but most regrettable is the lack of scientific studies and hard data. There were contributions that dealt specifically with the ecological impact of recreation in Britain (Ryle, 1967) and in Canada (Coleman, 1967; Edwards, 1967; Darling and Eichhorn, 1967), and also with the impact of the products of tourism and recreation (Kraus, 1967). These studies need now to be expanded by field research and provided with a more solid base from which conclusions may be drawn.

Publications of a practical value come from persons who are responsible for management decisions in the recreation field. Densmore and Dahlstrand (1965) discussed the applicability of erosion control practices originally developed for agricultural land to recreation-induced erosion problems. Among other topics they discussed erosion potential of a site related to the increased runoff created by soil

compaction and paved areas. The disposal of surface water must be planned to minimise this erosion hazard. Also discussed was the importance of a ground cover and its relationship to the canopy cover, as well as the usefulness of crop rotation principles in resting heavily used sites. Bohart (1968) in a somewhat similar vein, endorsed this idea of resting areas in rotation. He stressed that planning and design of a facility should endeavour to make over-use, and hence site degradation, an impossibility. Such design must consider the site limitations as well as the attractions.

As a final observation, it is interesting to note that the United States Forest Service (USDA) in providing guidelines for developing self-guiding trails (Forest Service, USDA, 1964) had little to offer in the brief section on trail maintenance beyond the picking up of visitors' litter and promptly replacing damaged signs and markers. Any other problems that may arise are presumably dealt with in the final sentence which pronounced that "good trail maintenance will spot potential hazards that can be eliminated before they become troublesome."

1.5.2 The Response of Vegetation and Soils to Treading

The studies which are the subject of this section have in common a scientific basis from which conclusions are drawn. They include work carried out over the last sixty years which contributes to the understanding of ecological problems generated in areas used for recreation.

Shantz (1917) recorded one of the first attempts to follow the process of revegetation of heavily used surfaces, in this case the abandoned roads on the grasslands of eastern Colorado. The nature of the tracks left by carriage wheels is similar to those of pedestrian use in that the ground is denuded of vegetation and the soil compacted. The tracks left by horses are different however, as hooves tend to cut

up and loosen the soil surface. Shantz concluded that succession on these roads differed from that on abandoned fields in only minor details.

The first study directly related to the effect of pedestrian treading on vegetation was by Bates (1935). He sought an explanation for the observation that the vegetation of a path is often very different from that alongside it. For several paths, data were collected on areal percentage (cover) of bare ground and for individual species, and the frequency and constancy of individual species. He recognised the importance of soil density but failed to obtain definite measures of it. The occurrence of 'puddling' (deflocculation of clay particles) was considered of prime importance to the survival and performance of the path species, although not considered to influence the species composition.

Bates hypothesised that the species resistant to treading must possess some common peculiarity of structure. This was supported by the discovery that the most resistant gramineous species were *Poa pratensis*[1] and *Lolium perenne*, both of which exhibit conduplicate stems, folded leaf sections and a cryptophytic life form, characteristics which offer some protection from damage by treading. In addition, *Plantago major* was found to occur on the footpath in a cryptophytic form and as a hemicryptophyte on untrodden areas, suggesting that life form was an important factor in the ability to survive. Bates also set up an experimental plot consisting of rows of different species across which a path was trodden daily, enabling him to compare the effects of trampling on these species. It is surprising that this detailed paper did not stimulate more interest as it contained many hypotheses to be tested and other points suitable for further research.

Following this first major study came three others in rapid

1. See Appendix A for a list of common names.

succession, two by Bates (1937; 1938) and one by Davies (1938). All stressed the idea that a zonation of vegetation is apparent and made the assumption that these zones result from the varying intensity of use, although there was no attempt to relate the degree to which the path had developed with its use. The most important conclusion drawn was that the life form of a species is of major importance in determining its ability to resist treading pressures.

In contrast to the studies of Bates and Davies, a study by Horikawa and Miyawaki (1954) in Japan singled out soil hardness as the most important contributory soil factor governing "treading associations". Haessler (1954; cited in Walter, 1960) followed the earlier lead of Bates and Davies in investigating various treading situations to determine the characteristics that confer resistance upon the "treading species" and their ability to reproduce and spread under adverse conditions. An immediately striking aspect of these widely separated studies is the frequency with which certain species are encountered. *Poa annua*, *P. pratensis*, *Polygonum aviculare*, *Capsella* spp., *Matricaria matricarioides*, *Plantago major*, *Taraxacum officinale* and *Trifolium repens* all appear repeatedly in studies of treading situations in temperate zones.

A study of forest picnic sites in Connecticut (Lutz, 1945) showed that the infiltration rate of water on picnic sites was severely impaired with heavy use. A heavily trampled sandy soil was found to be one-sixth as permeable as the same soil in non-used areas, and a sandy loam soil only one-twentieth as permeable as its non-used counterpart.

A review of the effects of soil compaction on forest and range lands by Lull (1959) brought out a point which is significant to recreation situations. He stated that forest cover is important in maintaining a leaf litter layer to absorb the energy of falling raindrops that otherwise have a compactive effect on the bare soil. The statement that "their (rainfall impact and surface runoff) most important effect may be the continuation of compaction after disturbance has ceased" is eminently applicable to the question of resting a recreation site or revegetating a disturbed area.

Wagar (1964), recognised the need to determine carrying capacity of recreation sites, and tried to establish a relationship between use and the vegetation response by simulating treading on experimental plots. The plots were harvested at the end of the experiment and multiple regression equations were derived for production and 'use'. 'Use' was determined by dropping a tamp on the plot, and these data are therefore fairly limited in their applicability. The change in composition of the ground cover, an important aspect of any treading situation, was not considered. Tamping must be correlated with actual treading pressures before it can be used in a predictive model, and an important aspect of treading that it cannot simulate is the rotary twist applied by the foot in walking (Bates, 1938; Davies, 1938). The conclusion that no apparent threshold was found beyond which additional tamping caused accelerated site damage must be viewed with caution.

Campgrounds in Rocky Mountains National Park, Colorado, were the subject of a study by Dotzenko, _et al_. (1967). They evaluated relationships between bulk density (a measure of soil compaction), soil moisture and organic matter using correlation and regression techniques for sites with different levels of recreation use, but had

to conclude that more research was needed. They also noted that techniques and methods should be developed to study the effects of many factors on campground environments, an indication that perhaps traditional methods should be replaced.

1.5.3 Ecological Studies of Recreation Sites

A major landmark in the so far rather haphazard development of recreation ecology was the publication (Duffey, 1967) of papers from a British symposium on the biotic effects of public pressures on the environment. The introduction acknowledged that factual data and experimental results were extremely meagre, but suggested that it was time for general discussion and collaboration on topics including the effects of public activities on Nature Reserves, mountain habitats, woodlands and hedgerows, coastal habitats, and grassland areas. Only those particularly relevant to this study will be commented on here.

Watson (1967) outlined the problems that have arisen in skiing areas in the Cairngorms and the proposed research methods for studying them. The results of this study were detailed in a later paper (Watson *et al*., 1970); soil erosion was monitored by mapping the area of damaged ground once a year, and work was begun on compaction and infiltration. Trampling studies isolated indicator species that respond uniformly to increasing pressure. Reseeding experiments were conducted using commercial seed mixtures, necessitated by the problem of soil erosion. This raises the question of the ethics of seeding with non-native species, especially in an area under protection. However, it is expected that, when not supported by fertiliser treatments, these commercial species will be succeeded by indigenous species. Research into the behaviour of people on paths and those who deviate from the paths is currently being conducted. A study of human pressures

on another mountain environment, Snowdonia in Wales, led Goodier (1967) to conclude that we must consider designing environments which will withstand human pressure.

Methods of estimating visitation were discussed by Hammond (1967) and divided into those that were manual (e.g. plotting visitor numbers and positions on a map) and those that were automatic (e.g. photo-cell counter, electro-magnetic counter operated by pressure on the lower bar of a stile, and time-lapse photography). However, no quantitative observations of the effect of various visitation patterns had been made at that time.

Perring (1967) described an interesting study of changes in species composition in chalk grassland caused by the galloping of horses. This study showed that the typical chalk grassland sward containing many species was converted by galloping pressure to an atypical, species-poor grassland.

In a recent series of papers (Marr and Willard, 1970; Willard and Marr, 1970; 1971) the visitor impact on alpine tundra was examined in Rocky Mountain National Park, Colorado. A scale of visitor effects was developed to sample the vegetation, but no attempt was made to relate this to the numbers using the area. The ecosystems were ordered according to vulnerability, those with high soil moisture being the most affected, followed by tall herb systems and fellfield. Turf types were found to be the most resistant. Enclosures and the channelling of visitors, so that a known amount of use was received, led to the conclusion that an area that has been trampled for one year will almost completely recover in four years. The prospect is less hopeful for sites that have been used for a longer time; one showed no improvement in four years of protection having

sustained severe damage through thirty-eight years of use. The authors estimate that some sites which have been damaged by only a few seasons' use will take hundreds if not a thousand years to fully recover.

A study concerned with techniques for examining the effects of recreation pressures is that of Goldsmith et al. (1970). Questionnaires in the form of maps were used in the Isles of Scilly; from these, maps of the intensity of visitor use and the distribution of various activities were prepared. These were then compared with maps of plant communities. Detailed studies of vegetation along transects were compared to user-patterns (derived by photographic and photo-electric means) and soil characteristics by use of partial correlation analysis.

Three less formal studies are those of Barker (1967), Lindsey County Council (1970) and Huxley (1970). The first is largely a result of personal observation over a period of time, but no less valuable for its qualitative nature. The second is also a descriptive account, but is important as a report for a local government body from which future proposals affecting the environment will emanate. As shown in the Lindsey Project for the Improvement of the Environment it is important to involve both local voluntary bodies and the statutory authorities and to not consider recreation ecology only in an academic light. The third paper mentioned (Huxley, 1970) is an informal introduction designed to stimulate thought on countryside footpaths. He discussed the various types of natural path and foot-path construction on a variety of topographies and through different communities.

Fortunately, the volume of research on the effects of recreation

on the environment is rapidly increasing. There appear to be more detailed studies in Europe and particularly in Britain (although this may simply reflect the availability of material published in English) than there are in North America. This is due in part to the differences in recreation area and relative population sizes, although North Americans havein recent years come to realise that land is not an infinitely available resource. Europeans have been despoiling their environments for a longer period, but at a slower pace; the limited space and large populations require that action is taken to remedy the damage as soon as possible.

There is still however a great deal of research that must be carried out before it will be possible to base management techniques rather more on scientific principles than on intuition. The present study is an attempt to document some of the ecological effects of recreation resulting from the pedestrian use of trails.

1.6 The Purpose and Scope of the Present Study

This study is an attempt to quantify some of the variables connected with trail status. Trail status may be defined as the physical and biological attributes of the trail or path at a particular point in time, and includes soil compaction, width of the path and plant species distribution and abundance.

An important aspect of the study was to examine various appropriate field methods and to test them in a recreation situation. The preceding literature review illustrates that very few studies of this type have been conducted so far, and that there is no generally accepted methodology (although there have been many conclusions to the effect that this would be desirable). All agree that trampling is one of the most important factors contributing to the deterioration of a site, but also one of the least well understood. This study is therefore focussed on a channelled

treading situation, namely a path or trail, to document the changes occurring from the centre to the edge and then into the undisturbed vegetation.

Trails were chosen as the subject of a detailed study as they express, in a very concise way, a system of graduating recreational pressure from the centre of the path to its edges. Channelling of use gives rise to a more intensive pressure than would be experienced if the pressure was distributed over a larger area. A path may therefore be an indicator of the type of changes that would occur in an area if the pressure throughout the area was increased. Hence a path may be viewed as an expression of areal response collapsed into a linear form. This speculation has certain limitations; the linear form of the path and the close proximity of very different zones (bare ground to natural cover) will probably give rise to certain conditions that would not occur on extensive areas receiving identical pressure, and it may be impossible to identify the appropriate source. This concept may be retained as a tentative hypothesis and re-examined later.

Trail status is the outcome of a multiplicity of interacting variables. It was not feasible to attempt analysis of more than a few that are considered of prime importance. These are tested statistically and data are presented by various methods. A tentative model of the factors determining trail status includes variables that were not measured in the field, and relies primarily on theoretical considerations.

The Cypress Hills in southern Alberta were selected as the study site. This area is a Provincial Park with an increasingly popular lakeside resort and is currently experiencing an increase in recreational activities and visitation. Nature trails (self-guided) provided in the

late sixties were investigated by this study.

It was originally intended to relate use to the trail status. This was not possible however as the trail was investigated using transects perpendicular to its length; the position of trail-users on the transect was therefore required in addition to the absolute numbers crossing the transect. Collecting data of this kind would require at least mechanical aid in the form of photographic records, and would be facilitated by a team of researchers able to monitor more than a single point in space.

In conclusion, this study considers trail status, investigates methods of examining trail status, and tests some of these ideas in the field. Various ways of analysing and expressing the results of the data collected in the field are discussed and demonstrated. A model is offered for the factors determining trail status, based on observations, field data and theoretical considerations. Finally, trail management and suggestions for future investigations are considered. Appropriate here is an observation by Lucus (1966), specifically related to wilderness policy but also applicable to any ecological recreation research:

> "The potential returns of environmental research related to wilderness policy seem large. Many of the major problems seem insoluble without such research. Debate and dispute will never be eliminated by research, but they could be focussed on the really intangible value choices."

CHAPTER II

CYPRESS HILLS - PHYSICAL AND VEGETATIONAL ASPECTS

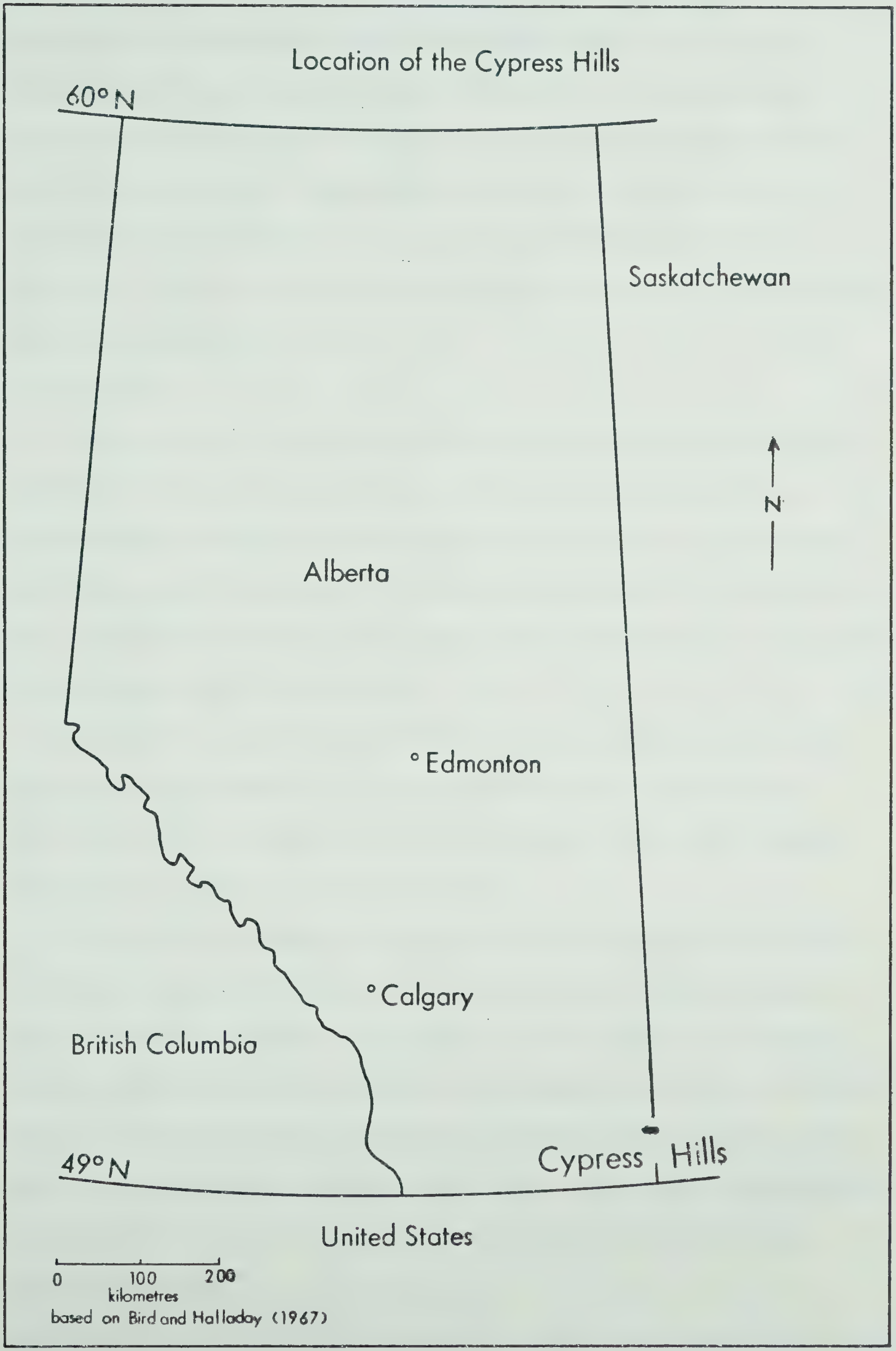
2.1 Location

The Cypress Hills cover an area of about twenty five hundred square kilometres in southern Alberta and Saskatchewan (Figure 2.1), rising to an elevation of 1,468 metres (about seven hundred and fifty metres above the plains) at the western extremity. In Alberta, the north and west margins of the gently sloping plateau surface drop steeply into coulees, or melt-water channels. During the Pleistocene glaciation, the continental ice-sheet from the north-east flowed around the Hills, reaching to an elevation of 1,372 metres and leaving an unglaciated nunatak. The southern slopes of the plateau are consequently far less abrupt than their northern counterparts.

The uniqueness of the Cypress Hills as the highest point between Labrador and the Rocky Mountains is doubtless a consequence not only of their position on the continental divide (as a watershed for rivers flowing both to the north and to the south) but also of the porous nature of the capping conglomerate which reduces run-off. Furthermore, the easily erodible Frenchman, Battle and Whitemud Formations are protected by the overlying resistant Ravenscrag Formation.

An alternate hypothesis for the preservation of the flat plateau surface is that it is a lateral erosional remnant midway between the pre-glacial Missouri and South Saskatchewan rivers (Crickmay, 1965).

Figure 2.1


Location of the Cypress Hills
60° N
Saskatchewan
N
Alberta
Edmonton
Calgary
British Columbia
Cypress Hills
49° N
United States
0
100
200
kilometres
based on Bird and Halladay (1967)

According to Broscoe (1965), the pre-glacial divide between the two major river systems was a ridge linking the Cypress Hills and the Sweetgrass Hills, and the drainage at that time was to the north-west and the south-east. The pre-glacial divide was submerged during glaciation and several large melt-water channels, notably that in which the modern Milk River flows, were cut through as the ice retreated. This drastic change in drainage pattern may also contribute to the isolation of the Hills.

2.2 Geology

The deposits of the Cypress Hills and its surrounding area yield evidence of three main occurrences in the past (Russell, 1965). These are the withdrawal of the Pakowki Sea giving rise to terrestrial conditions, and the subsequent invasion and withdrawal of the Bearpaw Sea, followed by erosion of the land surface and deposition of materials originating in the Rocky Mountains.

On the plateau the Cypress Hills Formation (conglomerate) caps the underlying formations. It is thought to have been deposited by a wide swiftly-flowing stream from the west (Irish, 1965), and is covered by a variable thickness of loess.

The Ravenscrag Formation is found below the conglomerate, and is a Paleocene deposit of shales, siltstones, fine-grained sandstones and coal seams. The Upper Cretaceous beds underlying the Ravenscrag are the Frenchman, Battle, Whitemud and Eastend Formations, the latter being a transitional zone into marine sediments and containing a coal seam which was mined in the Park until 1961. The Bearpaw Formation of marine shales below these deposits is continuous into the plains around the Hills.

2.3 Climate

With their isolated elevation the Hills experience increased precipitation and rather decreased temperatures. Medicine Hat, about sixty kilometres north-west of the Hills, has a daily mean July temperature of 20.6° C compared with 15° C in the Hills, and a mean yearly precipitation of 33 cm, 13 cm less than the Hills (Halladay, 1965). The high evaporation rates which help to maintain a prairie vegetation on the plains are reduced in the Hills. The north-facing slopes of the Cypress Hills are sheltered from the prevailing south-west wind and this, coupled with aspect, enables a forest cover to develop. There are not, unfortunately, long-term comprehensive weather records for the Hills.

2.4 Soils and Vegetation

Soils and vegetation of the Cypress Hills are closely related to elevation, aspect, and the moisture regime. Grey wooded soils are found on the plateau and north-facing slopes, often with only a thin A_1 horizon over an eluviated A_2; lodgepole pine (*Pinus contorta*) and white spruce (*Picea glauca*) are associated with this profile (Bird and Halladay, 1967). Brown, dark brown and black soils are commonly found under the grassland associations (Breitung, 1954).

Two major divisions of vegetation occur. The forests are on north-facing slopes and in valleys at high elevations where the otherwise prohibitive temperature and moisture regimes have been ameliorated; grassland is present under the more rigorous conditions of the south-facing slopes and on the lower plateau elevations that are exposed to the south-west winds. Lodgepole pine is the most numerous tree species, occurring at the highest elevations and as pure stands on the well-drained, warm soils of the conglomerate capping of the pleateau,

extending into mixed stands on the north and west slopes. It is believed to occur as a sub-climax (Breitung, 1954; Bird and Halladay, 1967) since the successional white spruce is prevented by frequent fires, notably the Great Fire of 1886 which swept almost the entire Hills. Following a fire, regeneration of lodgepole pine is favoured over white spruce by the pyric release of seeds from the resinous cones, by the rapid rate of ecesis, and by its shade intolerance. Since 1911, the forested area has been subject to fire control, and fires have been less frequent and extensive. There is still little evidence that young spruce are becoming established in pine stands however, although this has been reported from the Saskatchewan portion of the Hills (Breitung, 1954). Spruce tends to occupy the lower and more moist sites, often in association with aspen (*Populus tremuloides*), another species favoured by fire as it promotes the root suckering that is its primary means of propagation in the Hills (Newsome and Dix, 1968). Balsam poplar (*Populus balsamifera*) is also present in moist locations, although less abundant than the other three tree species.

The grassland, primarily fescue prairie (*Festuca scabrella* association) is favoured by fire and grazing from invasion by forest. In places, the black soil typical of grassland is found under aspen groves, indicating that the grassland-forest interface is not a fixed boundary, but fluctuates over the years.

An interesting aspect of the vegetation of the Hills is the well represented montane element. It is thought that little, if any, vegetation survived on the nunatak during glaciation, but that the climate after the ice withdrawal enabled a montane floral (and faunal) invasion from the uplands to the south and south-west. Some of these

montane species vanished as the climate became warmer and drier, and the survivors retreated to the higher elevations and cooler and moister sites with northern aspects. Of the 353 vascular plants recorded for the Hills in Alberta, some 39 or 11%, are montane (Bird and Halladay, 1967). Examples are lodgepole pine, bluebunch fescue (*Festuca idahoensis*), and pine-drops (*Pterospora andromeda*). The representation of a flora that normally is not encountered outside the Rocky Mountains suggests to some (Bird and Halladay, 1967) that a post-glacial forest link existed between the Rocky Mountains and the Cypress Hills, subsequently broken by the climatic changes. This idea was also suggested by Russell (1951), who found land snails with Rocky Mountain affinities present in the Hills and postulated an environmental link with the eastern slopes of the mountains.

The montane element contrasts with the southern flora and fauna, represented by species such as the sage grouse (*Centrocercus urophasianus*), which occurs here at the northern limits of its range. It should be emphasized however, that this southern element is to be found not in the forested area of the Hills, but in the region directly to the south. This area offers an even more extraordinary contrast with the Hills than the prairie to the north, having an annual rainfall of less than 25 cm in a gently rolling country of sagebrush and cacti. This juxtaposition of environments has led to various claims that sub-tropical and desert species are coexistent with sub-alpine elements, this occurrence being partially attributed to the isolation of a relict flora on the nunatak during glaciation. While not quite this incredible, it is nevertheless true that the Hills and surrounding area possess a unique and fascinating biotic complex, which studies are only now beginning to elucidate.

CHAPTER III

MAN'S OCCUPATION AND IMPACT ON THE CYPRESS HILLS

3.1 Historical Events

Recorded history covers only the last one and one-half centuries of man's activities in the Cypress Hills. Evidence of occupation prior to this was uncovered by archaeological excavations in a vale at the east end of Elkwater Lake during the summer of 1971; they offer a tantalising glimpse of man's presence several thousand years ago.

For many years the area of the Hills was a buffer zone between Blackfoot and Sioux, but in the second half of the 19th century it was used as a hunting ground. During the latter part of the century the Plains Indians increasingly occupied the plateau, and tensions increased between Indian groups as well as between Indians and white hunters. This conflict culminated in the Cypress Hills Massacre of 1872 when a band of American wolf hunters attacked a camp of Assiniboine. The attack on Canadian Indians prompted the formation of the North West Mounted Police and the establishment of forts in Alberta and Saskatchewan. The subsequent administration of the 'Medicine Line' - the 49th Parallel - is an important part of frontier history. The last two decades of the 19th century saw the passing of the buffalo and the establishment of cattle ranching and homesteading by white settlers, and thus this brief but eventful period was brought to a close.

3.2 Establishment of a Park

There is little recorded about the use of the Cypress Hills in the first part of this century. Almost certainly they were used for

grazing as the quality of forage was far superior to that of the surrounding prairie. Most of the information which follows was obtained from the Alberta Department of Lands and Forests. In 1906 a forest reserve of about two hundred square kilometres was established, but grazing within the boundary was continued through the issue of permits. In the period prior to the Great Depression, settlement and prosperity on the Prairies was increasing, and for those in the locality, Elkwater Lake (Figure 3.1) gradually became a popular refuge during the hot summers. By 1929 it was so firmly established as a summer resort that Elkwater Provincial Park was formed, comprising approximately seven and one-half square kilometres of land along the southern shore. Ironically, on this land set aside as a Park, the development of a small village led to a total of forty dwellings by 1938 and the townsite was withdrawn from Forestry administration. In 1945 an unoccupied area of slightly less than half a square kilometre within the townsite came under Provincial Parks Board to be administered as a public recreation area, and finally, in 1951, a total area of 199 sq. km including Elkwater townsite, became the Cypress Hills Provincial Park, Alberta (Figure 3.1).

3.3 Twenty Years of Park Development

Much of the development in the Park has taken place in the latter half of the sixties in response to the increasingly sophisticated demands of the visitors, as well as their increasing numbers. Some of the major developments are discussed in separate sections below.

3.3.1 Road Network

Not surprisingly, a comprehensive road network has developed in the Park, major sections of which have recently been paved. While it is perhaps necessary to upgrade a gravelled road if it is heavily

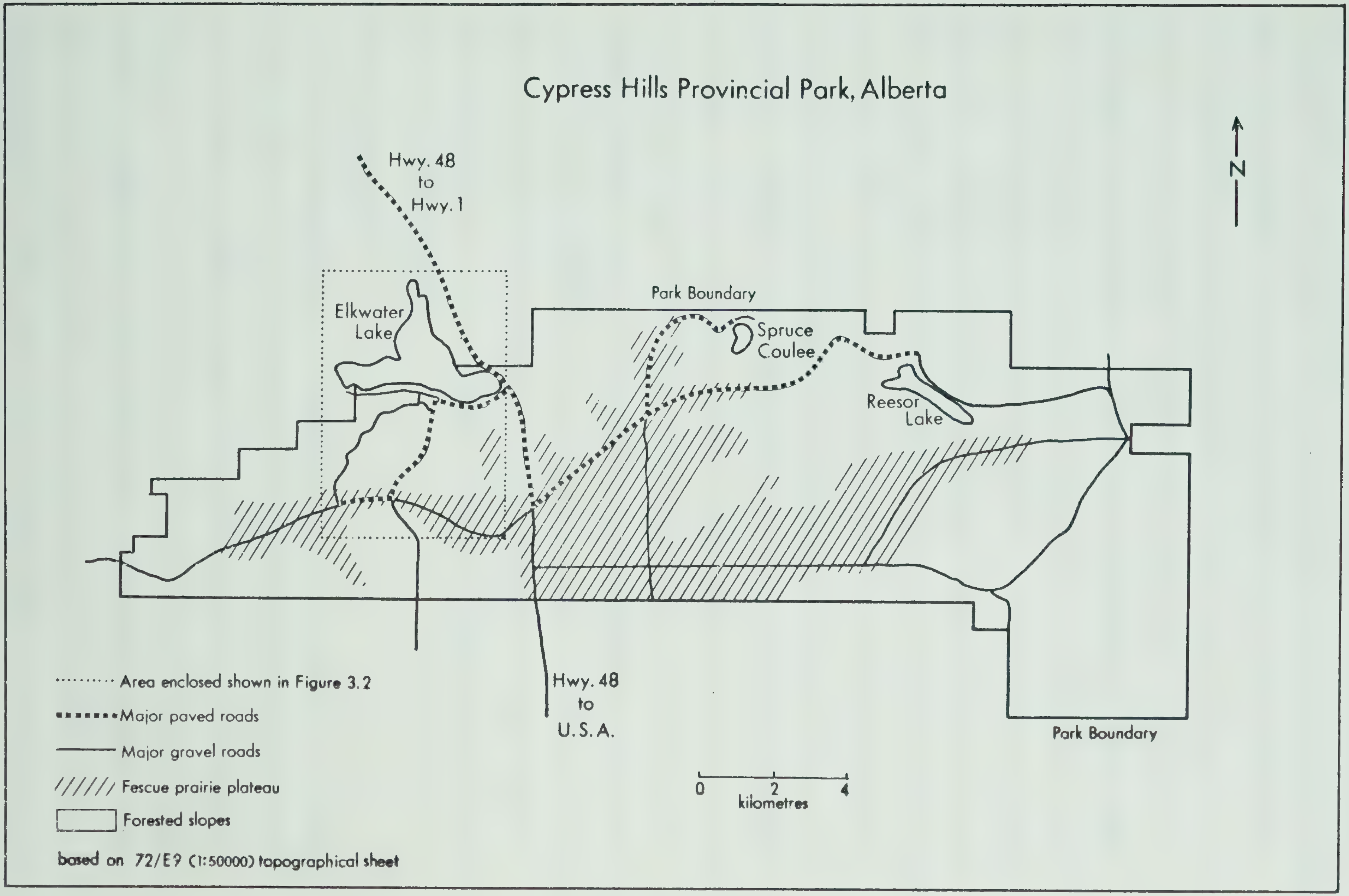

Cypress Hills Provincial Park, Alberta
N
Hwy. 48
to
Hwy. 1
Elkwater
Lake
Park Boundary
Spruce
Coulee
Reesor
Lake
Hwy. 48
to
U.S.A.
Park Boundary
Area enclosed shown in Figure 3.2
Major paved roads
Major gravel roads
Fescue prairie plateau
Forested slopes
based on 72/E9 (1:50000) topographical sheet
0
2
4
kilometres

Figure 3.1

travelled, it is also desirable to keep a park road in harmony with the landscape, and in places this has regrettably not been accomplished. This case is exemplified by the road carrying high speed traffic from the Highway 48 junction on the plateau to Reesor Lake (Figure 3.1). Its construction was such that roadside ditches twice the actual road width have been excavated to provide road base material. These areas have been invaded by 'weedy' species which have very different flowering characteristics from the adjacent grassland. The predominantly green and white appearance of the ditch provides an unattractive contrast to the colourful prairie flowers blooming beside it. The major ditch species are foxtail barley (*Hordeum jubatum*), milfoil (*Achillea millefolium*), dandelion (*Taraxacum officinale*), shepherds purse (*Capsella bursa-pastoris*), pineapple weed (*Matricaria matricariodes*), common knotweed (*Polygonum aviculare*), common plantain (*Plantago major*), Canada thistle (*Cirsium arvense*), white clover (*Trifolium repens*), and white sweet clover (*Melilotus alba*). The gravel roads, although less comfortable to travel, have the advantage of reducing vehicle speeds and hence reducing the risk to wildlife on the road. Such a reduction in speed should give the traveller a closer contact with, and a greater appreciation of, the area being traversed.

3.3.2 Campgrounds

Many campgrounds are provided both in the townsite and in other areas of the Park, and the overflow which often occurs at the height of the season has been accommodated on an open space in the townsite. Heavy use of the sites has destroyed all but the most resilient ground cover. In campgrounds in the pine stands, which have naturally sparse ground cover, often the only species remaining is the meadow sweet (*Spiraea lucida*). The sites in mixed forests seem to fare better, but

it is interesting to speculate whether campers will continue to use a campground that has been trodden bare of vegetation and is dry and dusty, if they can find one with less deterioration.

3.3.3 Beach and Marina Facilities

The marina was first built in 1961 and rebuilt to its present dimensions in 1966. Presently there are moorings for eighty craft. There were vacant moorings for the first time in 1971 after several years of being over-subscribed. A reduction in the number of powered craft can only be an improvement in terms of the small size of the lake and its pollution by motor wastes. Furthermore, the sound of the more powerful boats on the lake carries well up into the hills.

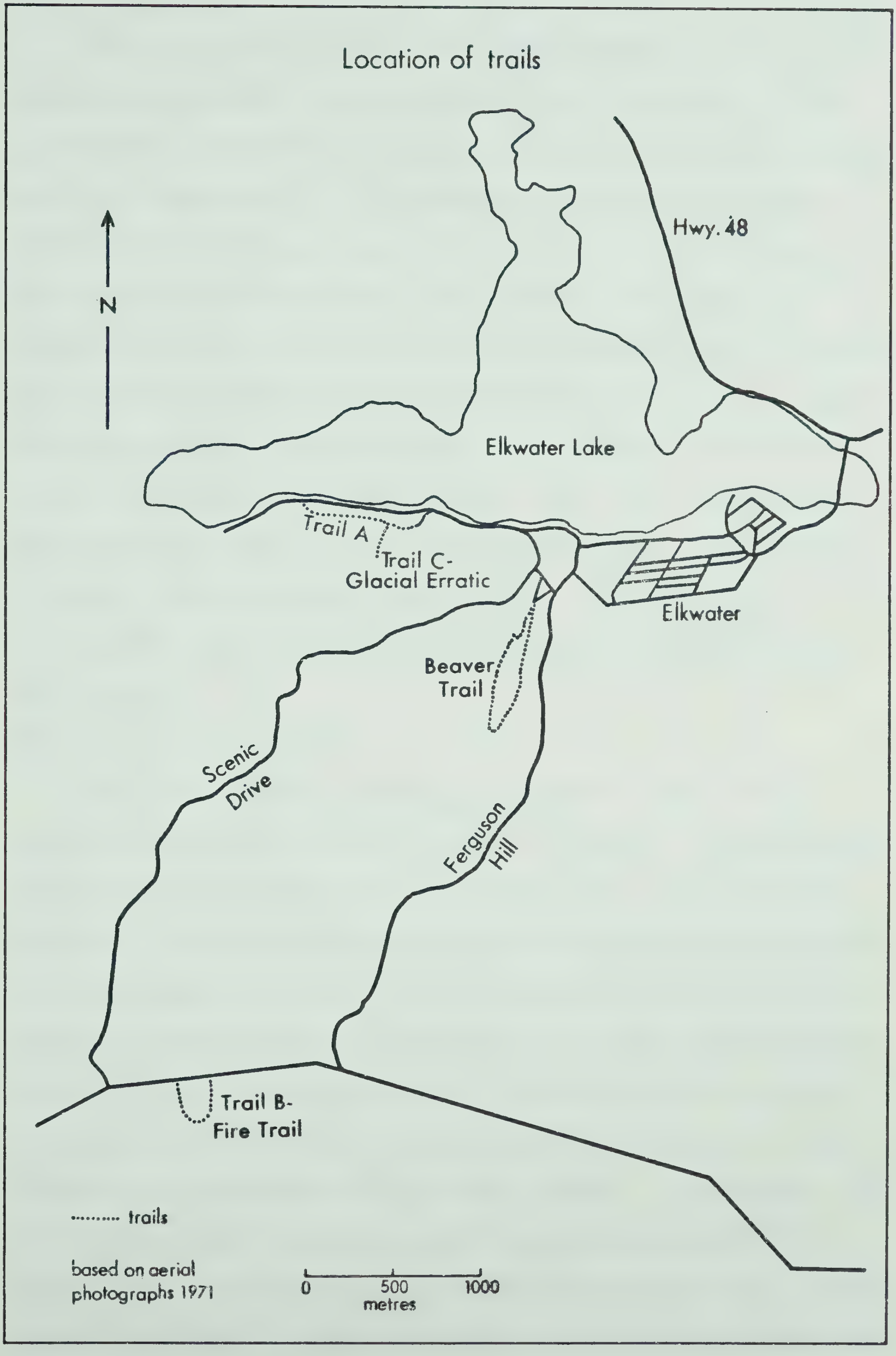
Swimming, another lake-oriented family activity, seems conversely to be on the increase. In 1965 sand was spread to form a beach and a life guard service was provided for public safety. There seems little likelihood of the beach losing its popularity, and the grassed area between it and the road is effectively maintained against pedestrian traffic by the use of water sprinklers. Where there is no water shortage this is an effective dual-purpose management tool.

3.3.4 Trails

The trails, which are the subject of the detailed study which follows, were also established in the late sixties. Beaver Creek Trail and the Glacial Erratic Trail to the west of the townsite (Figure 3.2) were formally set up in 1967. The latter was originally a cattle trail and the former was a game trail that was subsequently widened. The Fire Trail is situated in a lodgepole pine stand on top of the plateau (Figure 3.2) and was first set up in 1968. It was closed during the next two seasons and re-opened in 1971. The trails are discussed individually below.[1]

1. The information on management was supplied in August 1971 by Mr. A. Salus, Park Manager.

Figure 3.2


Location of trails
N
Hwy. 48
Elkwater Lake
Trail A
Trail C-
Glacial Erratic
Elkwater
Beaver
Trail
Scenic
Drive
Ferguson
Hill
Trail B-
Fire Trail
trails
based on aerial
photographs 1971
0
500
1000
metres

Beaver Creek Trail

This trail runs to several beaver ponds through a valley of mixed spruce-poplar woodland interspersed with grassy open spaces. It is approximately two kilometres in length, and is the only trail receiving any form of maintenance. The overhanging grasses are handscythed twice before July of each year. The trail runs from and returns to the south end of a trailer park, and is popular with campers who frequently walk it in the evening to see the beavers (*Castor canadensis*). This trail is self-guided by means of numbered posts along its length and an accompanying leaflet which has to be obtained from the Park Office. Originally a box containing the leaflets was placed at the beginning of the trail, but vandalism and scattering of the pamphlets led to the discontinuation of this practice. The Park Office estimated that over five thousand leaflets are distributed each year for this trail.

Fire Trail

This trail runs from a point opposite the Fire Tower, where parking and information display boards are provided. It passes through an old stand of pine into an area that was burnt in 1934, the Willow Creek Burn. Dense regeneration has occurred and trees are overstocked and ground cover is sparse. The path was cut through the trees and is presently marked by its lack of organic cover. Most of the season the surface is very dry and dusty. Metal signs give details of interest along the route. This trail is a short ten minute loop, and is considered by the Park Office to be the most popular. An estimate by the Fire Officer on the number of people using the path per day at the height of the season was from eighty to one hundred and fifty carloads.[2] Personal observations suggest that this is too high, and that fifty to one

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2. The average carload is three people.

hundred carloads would be more accurate, although this was based on only a few days survey. The Fire Trail is an attempt to create an awareness in the public of the longstanding consequences of forest fires. It also presents a disturbed aspect of the natural environment as contrasted to a conserved area such as the beaver ponds.

Glacial Erratic Trail

This trail goes to a glacial erratic that sits on a grassy knoll. The trail initially runs parallel to the road by the lake (Figure 3.2) through a spruce-aspen woodland, then branches off and climbs steeply through a narrow belt of pine before reaching the erratic. On the steep slope the trail is incised in places up to twenty centimetres. The same system of station markers and an explanatory pamphlet is used here as on the Beaver Creek Trail. However, as the turn-off from the trail parallel to the road is at a steep angle, overgrown, and on a bend, and since the marker is not well displayed, people frequently miss it and walk the length of this trail instead. This path parallel to the road is prone to slumping, probably because of the coal mines in the vicinity, but this has not been deemed serious enough to warrant preventative measures. The Park Officer estimated that less than five thousand leaflets were given to tourists for this trail.

During the hottest part of the season, when temperatures may be 29-34° C., it appears from personal observations and from those of the Park Manager that there is a distinct quiet period from about noon to 3:00 p.m., both for vehicles and for pedestrians. Visitation was highest on the trails during the mid-morning (9:00 - 11:00 a.m.) and late afternoon (3:00 - 5:00 p.m.) periods. Guided hikes are led by Park Naturalists to Beaver Creek and to the Glacial Erratic as part of the Lodge Programme which also provides displays in the Lodge, slide

talks on geology and flora, films, and car-tours. In the 1971 season of May to September, 332 people joined the guide hike to Beaver Creek, and 165 to the Glacial Erratic, a total of 497. A further 206 joined the hike to the plateau from the lakeside, a rather more arduous walk of seven kilometres, which takes two hours to complete. This grand total of 703 for three hikes per week compares quite favourably with the total of 838 for the two car tours per week. These guided tours have now been running for three summers and all are increasing in popularity; this is especially true for the car tours, which have the greatest rate of increase.

CHAPTER IV

FIELD METHODS AND LABORATORY ANALYSIS

4.1 Methodology - Theoretical Considerations

There is little published information dealing with quantitative investigations into the nature of trails and hence there is no established methodology. A choice is therefore offered between adapting classical ecological methods to this particular field situation and devising new methods with an entirely different perspective. The latter approach, although more challenging, would probably be easier to accomplish through insights gained from some of the problems encountered in classical field studies. In either case, a desirable objective is to minimise the time and effort spent in the field and laboratory and to maximise the information output.

4.1.1 Trail Zonation

Trails may be studied in at least two ways; one may consider the changes that occur across a trail or, in a different dimension, one may view the trail as a linear feature composed of parallel zones, the characteristic properties of which may be studied. The latter concept is easier to handle theoretically as there are measurable differences between the well-trodden centre of the path, and points on either side where the effects of the path are minimised. It is a moot point however whether these changes would occur in discrete steps and produce well-defined zones. Furthermore, if such zones did occur it is questionable whether they would be visible; species distribution, success, and other plant indicators arise as a result of the interaction

of numerous biotic and abiotic variables, including the toleration of inhospitable conditions. One might reasonably expect an overlapping of tolerance ranges to a multiplicity of conditions; there is also the random element which may occur in every plant distribution. If zones were not visually distinguishable they could hardly be used as a basis for the sampling plan and sampling to establish such zones would involve an unavoidable circularity. It is perhaps more reasonable to assume that changes across the path will occur in the form of a continuum, and in this case the cross-sectional approach offers greater applicability.

In this study an attempt has been made to keep the sampling sufficiently flexible to embrace both cross-sectional and zonal aspects. Unless some form of zonation is applied it becomes very difficult to relate one cross-section to another, and hence to generalise from particular cases. The problem is therefore to set up a system of zonation with categories sufficiently broad that they will be simple to assign, yet still display real differences. Spatial distance is of limited value as the width of the trail is variable; therefore it is necessary to use some form of weighted distance value, or to redefine distance in terms of trail characteristics. The amount of bare ground was used as the criterion in this study. It is argued that there will be measurable differences in the soil and vegetation properties from areas of completely bare ground to those where natural vegetation is found. The maximum differences will therefore occur between the centre of the path and the zone least affected by the trail, i.e. farthest from its influence. As the transect cannot be of infinite length, this latter zone is assumed to start, for practical purposes, at a distance two to three times that of the trail width from the edge of the trail.

This may even be reduced to one trail width in woodland where the understorey is dense and often prickly, and there is little if any movement away from or alongside the trail. This is of course only a general guide and if field inspection indicates it to be unsatisfactory, the transect is extended until it appears visually to satisfy the requirements of undisturbed vegetation.

4.1.2 Sampling Strategy

Several constraints became apparent when the sampling strategy was being considered, engendered in part because the work was carried out on trails in an established park. Non-destructive methods that would create minimum disturbance were therefore essential. It was decided to sample soils at five points only on each transect: path centre (one sample), path edges (two samples), and away from the path (two samples). This pattern can be interpreted as representing three or five zones, depending whether a symmetrical or asymmetrical distribution of characteristics about the centre-line is assumed. This selection of sampling sites immediately raised the question of defining the path and its edges, so that consistent decisions could be made for each transect under consideration. It was considered undesirable to define the path in terms of any of the variables being measured, but equally inadequate to determine the edges purely on visual grounds. It was noted however, that a visible discontinuity was apparent on the Fire Trail, primarily because of the scarcity of organic litter on the path and the lowered trodden channel. The path was finally defined somewhat arbitrarily in terms that seemed to agree with visual estimates for the Beaver Creek and Erratic trails, as lying between those points where the amount of bare ground exposed was 50%. The exact method used for determining these points is

described in the section on field sampling. This method is based on subjective grounds, but was applied in an objective manner. It is probably true however, that the arbitrary value chosen would not be appropriate for all trails, and that 25%, 75% or any other value could be used under other habitat conditions. The consideration of the zonal concept and the delimitation of the trail have therefore given rise to the working definition of a trail as a function of the amount of bare ground.

4.1.3 Transect Analysis of Vegetation

Transect analysis is often quoted as an appropriate method of studying environmental gradients and ecotones (Cain and Castro, 1959; Phillips, 1959; Grieg-Smith, 1964; Kershaw, 1964; Daubenmire, 1968). More attention is generally focussed on areal sampling by means of quadrats, but given a reasonably well marked variation in vegetation, line transect and intercept methods may be equally valuable. It was decided to locate the transects randomly so that the data could be analysed statistically and presented graphically; this is later discussed in more detail.

The vegetation was sampled along the transect using a point quadrat. This is a frame through which pins may be lowered and the species which they touch recorded. Cover is defined as the proportion of the ground occupied by perpendicular projection on to it of the aerial parts of individuals of the species under consideration (Grieg-Smith, 1964). It may be estimated visually, using for example the Braun-Blanquet (1932) scales. These however are prone to subjective error and hence are better used for surveys of large areas than detailed estimates of abundance. Cover may be measured quantitatively by selecting a number of points within the area considered and determining

cover for these alone. The use of point quadrats has been extensively discussed by Goodall (1952). The main source of error is caused by the diameter of the pin. The pins used were therefore sharpened to a fine point, and only contact with the point was recorded to avoid overly high estimates of the cover. An optical cross-wire method has greater accuracy as it is equivalent to using a pin diameter of zero, but is of less practical value in dense vegetation. As the data were required primarily for comparative purposes, and as a constant pin diameter was used, the exaggeration of percentage cover from site to site is not likely to be important.

4.1.4 Soil Compaction

Bulk density was chosen to be the best indicator of soil compaction, but collecting a sample with known volume for bulk density determination poses numerous problems. The use of a penetrometer was considered, but rejected for the following reasons. The pocket penetrometer has a large error margin of ± 20% and measures, by means of spring deformation, the unconfined compressive strength of the soil. This cannot be converted to a value for bulk density, and only the upper 0.6 cm of the soil can be tested. The Procter penetrometer uses a graduated 20 cm penetration needle and is more accurate. It can be used to estimate wet and dry density and therefore compaction. Curves are established in the laboratory for moisture content with bulk density and penetration resistance for that particular soil. A field measurement of penetration resistance then establishes the moisture content, and this together with the wet density can be used to estimate the dry, or bulk, density. The penetrometer is most accurate for clay and silty clay soils. It cannot be used with any reliability on soils of coarser texture or on dry soils (Davidson,

1965). It was anticipated that both these conditions would be encountered in the field area and the penetrometer was therefore not used.

Bulk density is the ratio of the mass to the bulk or macroscopic volume of soil particles plus pore spaces in a sample (Blake, 1965). The problem in sampling is therefore to obtain a known volume. Two approaches are widely used - the core and excavation methods - of which the latter is the more accurate, but requires determination of the volume of the hole remaining after the sample has been removed. The core method involves forcing a cylinder of known volume into the soil to obtain the sample. Excavation methods necessitate transporting a medium into the field to fill the pit; suggestions vary from water in a rubber balloon which can be used for each sample, to sand and corn grains which are poured loose into the hole. Lutz (1944) even suggested making a plaster cast in the pit. It was felt that under the field conditions of this study the core method would be more practicable, particularly as the water content can also be obtained from the same sample. The hole which remains after removal of the core can be refilled with soil.

Only a small sample could be removed in the field because of the need to use non-destructive methods but as the core diameter decreases, the disruptive edge effect of inserting the corer becomes more pronounced so that very small samples may give erroneous values. Soil corers are available commercially and others have been devised from other tools; Mason (1948), for example, used a sharpened "Flit" gun. It was suggested that lengths of thin-walled Dural or copper tubing would be adequate, and that the depth of cylinder should be approximately one and one-half times its diameter.[1] Copper tubing with a

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1. Pers. comm. S. Thomson, University of Alberta.

diameter of 2.5 cm was cut to size and the rim filed to a sharp edge. Opinion is divided on the best way to insert the corer to cause the minimum disturbance. Dortignac (1950) favoured a constant pressure to push the corer in as he found that hammering shattered the samples; he enlisted the aid of a hydraulic jack under the bumper of a truck. Jamison et al. (1950) produced a hammer-driven core sampler, a modification of the sampler used by Lutz (1944), which they found preferable for compact soils, although pushing was more accurate in dry or wet soils. In wet soils, friction along the cylinder walls and vibrations from hammering cause a viscous flow of soil and result in values too high. Compression may also occur in dry soils if unconsolidated, and in hard soils if the hammering shatters the sample (Blake, 1965). Whatever the moisture condition of the soil, if more than an occasional stone is present the sample will give unsatisfactory results. The corer was hammered in this study as the soil was too compacted to allow the corer to be pushed in.

4.1.5 Soil Microtopography

A measure of the transverse profile of the trail was also sought. The form of the path itself will affect the distribution of people on it. Such microtopography will also provide different microenvironments which are thought to be of importance in seed germination (Harper et al., 1965) and may therefore influence the ability of species to revegetate a path that has been heavily used. In the above study a variance measure of the degree of roughness of the soil surface was made, the so-called "soil microtopographical variance (S.M-T.V.)". Germination experiments were then conducted on controlled soil surfaces of different S.M-T.V.'s, and it was concluded that two contrasting conditions may be expected to occur in the field. In one case

the population size may not be limited by the availability of suitable microsites and in the other a relatively low population size will be maintained by the lack of suitable microsites even with a high sowing density. In this case, the regulation of population density is not, it is suggested, density-dependent.

The technique of assigning a variance value to indicate the relative roughness of a surface was extended to this study. Its possible application to field studies was indicated by the above study, but there has been no use made of it as yet in recreational impact studies. Vertical measurements were made from a taut line across the trail. A similar method to determine the lowering of a trail (Burden, 1969) used a slotted angle iron, supported on pegs at the edge of the path, through which a ruler could be inserted. The practicalities of field work, however, favoured a less cumbersome tool. The slack on a taut nylon line should only amount to one or two millimetres over these distances (New Scientist, 1971), and this was considered an acceptable error quantity.

4.1.6 Visitor Use

It was also hoped to monitor the numbers of people using the trail, but without some kind of mechanical aid this was impossible. The use of photoelectric devices and time-lapse photography are discussed in a later section (Chapter VI).

4.2 Field Sampling

The trail was first surveyed generally, the distances being paced out, and a Brunton compass and Abney level used for the direction and degree of slope in each section. Transect sites were selected using a table of random digits and located by pacing.

At each site, 25 cm square quadrats were placed on both sides of

the trail such that an estimated 50% of the enclosed area was bare ground. The centre points of the quadrats were then taken as the 'edges' of the path, and a taut marker line was taken through them using surveying pins, and extended into the vegetation beyond the trail on each side. The following measurements were then made in the order given:

i. Trail width. This is the distance between the centre points of the quadrats mentioned above, perpendicular to the length of the trail. The centre of the trail is also arbitrarily defined as the midpoint along this width.

ii. Soil microtopography. Vertical measurements from the taut marker line to the ground surface were taken at 10 cm intervals over the width of the path. The marker line was divided into 10 and 25 cm sections for this purpose. The slope of the line was also taken, so that all values could be corrected to a common horizontal baseline.

iii. Vegetation. Species cover was recorded using a frame of ten pins, with a 5 cm spacing between pins. The point quadrat was orientated perpendicular to the transect line and placed at 25 cm intervals, starting from the centre of the trail and continuing into the well-vegetated areas beyond its edges.

iv. Soil cores. Cores were taken from the centre, edges, and last quadrat positions on the transect, a total of five for each site. The corer was hammered in starting at the first mineral soil horizon (A_1) until the top of the corer was flush with the soil surface. The corer was carefully dug out with a trowel, and the soil core immediately sealed in a polythene bag.

v. Soil samples. These were taken at the same places as the soil cores and to the same depth after the cores had been removed. Samples of 200-300 gm were placed in air-permeable bags for storage until they could be dried in the laboratory.

vi. General site description. A brief note was made of the vegetation within a 5 m square around the transect, including the amount of organic litter on the path and the degree of shading.

The most detailed sampling was done on the trail which ran parallel to the road by the lake, designated as trail A. The Fire Trail is referred to as trail B, and that to the Glacial Erratic as trail C. These trails are shown on Figure 3.2. Outlined above is the procedure which was carried out for trails A and C. On trail B, no attempt was made to collect soil cores and soil samples as the trail was too compacted; it was also very dry and fairly sandy, both conditions which cause the reliability of such methods to be in doubt. Further problems were encountered in the lack of ground cover beside trail B, and it became meaningless to define the edges of the trail in terms of 50% bare ground. The following modifications were therefore adopted for trail B:

i. As the trail is sited on the plateau on reasonably flat terrain, it was not levelled; however it was surveyed roughly in terms of paced distances and compass bearings.

ii. The edge of the trail was established on the basis of the amount of organic litter present, the position of trees bordering the path, and in particular the point where the trail had become lowered relative to the undisturbed area on either side. A trail of this kind was easier to delimit by eye than trail A or C.

4.3 Laboratory Analysis

The soil samples were dried at 35°C and passed through a 10-mesh (2 mm) sieve. Procedures for analysis were as follows:

4.3.1 pH

A 1:2.5 (weight) ratio of soil to water was used, i.e. 20 gm of soil to 50 ml of deionised distilled water, in accordance with the recommendation by the Soil Reaction Committee of the International Society of Soil Science (1930). This means that readings are likely to be higher than if made immediately upon the fresh soil when there is a suspension effect, due to contact with high concentrations of cations on the soil colloids (Jenny et al., 1950). An average difference of 1.6 pH units was measured by Gorham (1960) between direct electrode insertion and soil solutions for mulls in the Lake District, England. For this study the soils were stirred three times with a ten minute interval between stirrings. The reading was made with a glass electrode pH meter when the soil solution had settled for thirty minutes after the final stirring. This period of an hour between making the soil solution and taking the reading has been found to give more consistent results than longer or shorter periods (Vezina, 1965).

4.3.2 Organic Carbon

There are several methods of determining the amount of organic carbon present in a soil sample. One of the more rapid is to determine the loss of weight on ignition; the sample, pre-weighed, is heated in excess of 400°C in a muffle furnace. It is assumed that the loss of weight that occurs is due solely to organic carbon compounds. This is not necessarily the case however, and as there is

no indication of the quantities of other materials also released during burning, the method yields approximate results rather than an accurate analysis. Chemical methods may yield more reliable results, but are extremely time-consuming. The Walkley and Black (1934) rapid wet oxidation method with chromic acid requires only a minimum amount of glassware and standard chemicals, but relies on the digestion of organic compounds by the chromic acid using the heat generated by concentrated sulphuric acid, and a subsequent back-titration with ferrous sulphate. Its accuracy hinges on the recovery rate which is unknown, and may vary from 70-80% for a soil containing a moderate amount of organic carbon.

Since the methods described above were not considered to be very satisfactory, a combustion method to determine the total carbon content was used. If no inorganic carbon in the form of carbonates is present, then total carbon may be assumed to be the organic carbon content. Accordingly, small portions of each sample were treated first with a couple of drops of water to displace the air, and then a few drops of 4N hydrochloric acid. Effervescence, indicating carbonates, would necessitate a separate volumetric analysis to establish the quantity so that it could be subtracted from the total carbon leaving the organic carbon content.

The sample was finely ground to pass a 100-mesh (0.419 mm) sieve so that a large surface area would be exposed to the oxygen during combustion. A Leco 577-100 induction furnace and gasometric analyser was used. A weighed sample of 0.10 to 0.25 gm, depending on the estimated carbon content, was placed in a ceramic crucible with an iron chip accelerator; the latter, being a better conductor of heat than soil, ensures a thorough distribution of heat through

the sample. The sample is heated in a closed combustion tube by high frequency electromagnetic radiation to a temperature in excess of 1,700°C. Oxygen is passed over at a rate of 1.5 l/min. All the carbon in the sample is converted to oxides, and the gas stream passes first through a dust trap, then a catalyst furnace to convert carbon monoxide to the dioxide, and finally through manganese dioxide to absorb sulphur gases. The CO_2-O_2 mixture is collected in a burette over sulphuric acid, in which it is insoluble. The gases are then passed into a caustic potassium hydroxide solution to absorb the carbon dioxide; there is therefore a measurable volume change when the gas (now only oxygen) is returned to displace the acid in the burette. A correction is made for temperature (readings are taken of the temperature of the burette solution) and atmospheric pressure as the measurement is of a volume of gas. The calculation of total carbon content is as follows:

$$\%C = \frac{k(x_n - x_o)}{W_n}$$

where: k is corrected conversion factor

x_n is final burette reading for sample n

x_o is final burette reading for blank

W_n is weight of sample n

The values may be quoted as 'percentage organic carbon' (with the abovementioned proviso that no inorganic carbon is present), or converted to 'percentage organic matter' using the standard conversion factor of 1.74. As this factor may not be a constant for all forms of organic material, the values in this case have not been converted but were left as 'percentage organic carbon'.

4.3.3 Bulk Density and Related Variables

i. Bulk density

The weight of the core in the moisture condition in which it was sampled was determined by weighing it in the sealed polythene bag and subtracting the bag weight. Cores were then placed in aluminium containers of known weight and dried at 105°C for 24 hours; loss in weight is assumed to be due solely to the evaporation of uncombined water from the sample. The calculation of bulk density is as follows (CGS units are used throughout):

$$D_b = \frac{M_s}{V_b} \qquad \ldots 1$$

where: D_b is soil bulk density

M_s is the oven dry mass of soil

V_b is the bulk (field) volume

ii. Water content

This quantity is calculated from weighings made during the bulk density determination as follows:

$$P_w = \frac{W_s - M_s}{M_s} \times 100 \qquad \ldots 2$$

where: P_w water content on a weight basis

W_s is the initial total mass of the soil sample

The above equation (2) gives the water content as a percentage of the oven dry weight of soil, and is completely independent of the volume of the sample. The water content on a volume basis may be found as follows:

$$P_v = \frac{V_w}{V_b} \qquad \ldots 3$$

where: P_v is the water content on a volume basis

V_w is the volume of water lost on drying

Assuming the density of water to be 1 gm/cc, this may also be expressed as:

$$P_v = P_w D_b \qquad \ldots 4$$

iii. Porosity

Total porosity is that percentage of the bulk volume not occupied by solids, and may be calculated as follows:

$$\text{let } D_p = \frac{M_s}{V_p} \qquad \ldots 5$$

where: D_p is the particle density

V_p is the volume of the particles

from the above equation (5) it follows that:

$$V_p = \frac{M_s}{D_p} \qquad \ldots 6$$

from equation 2:

$$V_b = \frac{M_s}{D_b} \qquad \ldots 7$$

Hence:

the fraction of the total volume occupied by soil particles

$$\frac{V_p}{V_b} = \frac{D_b}{D_p}$$

Total porosity

$$S_t = 100\ (1 - \frac{D_b}{D_p})$$

$$= 100\ \frac{(D_p - D_b)}{D_p} \qquad \ldots 8$$

A value of 2.65 gm cm^{-3} is generally assumed for the particle density of mineral soils.

Air-filled pore space gives an indication of the amount of total pore space filled by a gaseous as opposed to a liquid medium, and is found by subtraction of the water content on a volume basis from the total porosity:

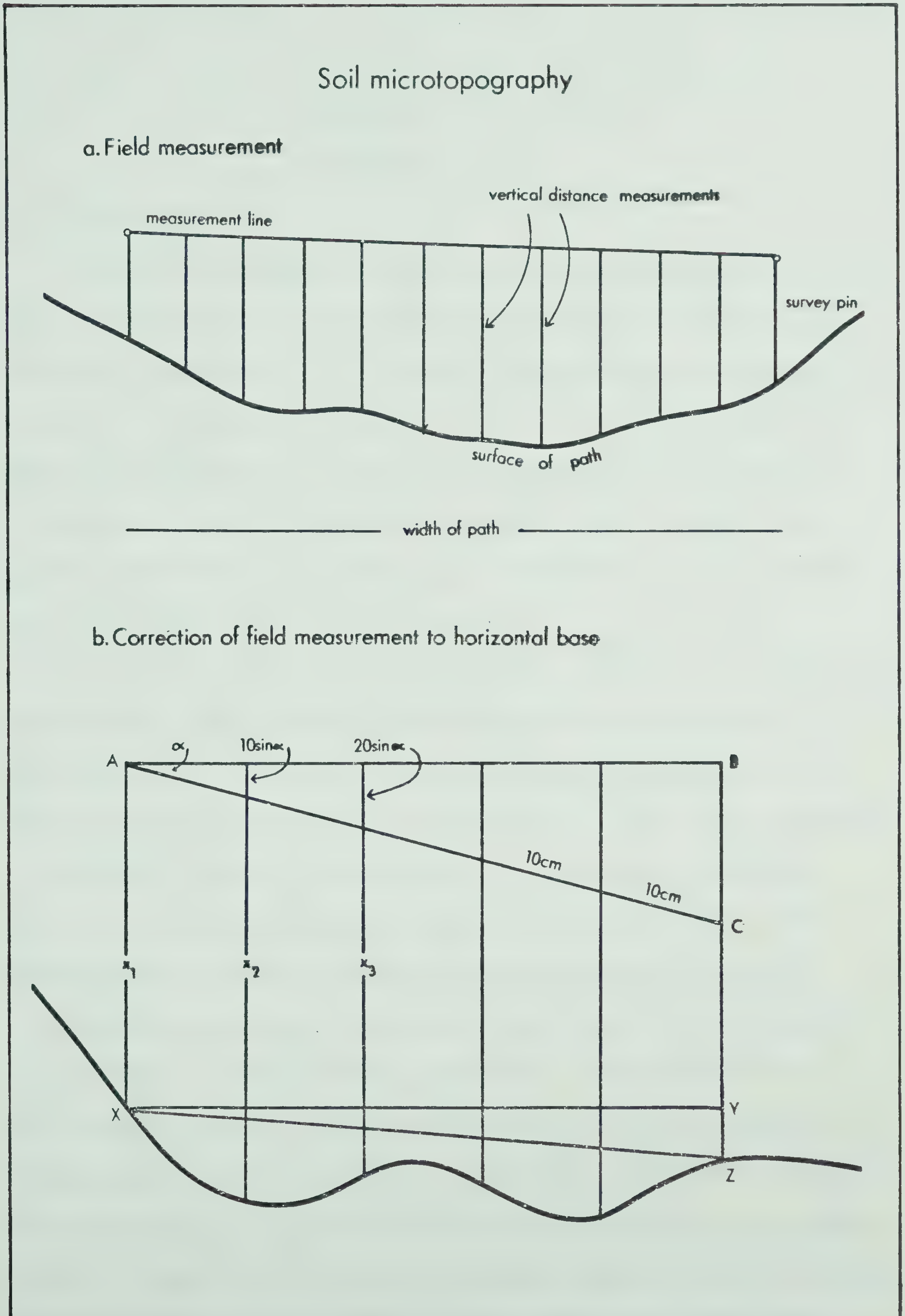
Air filled pore space $S_a = S_t - P_v$ ...9

4.3.4 Soil Microtopography

As it was often not feasible to level the line from which measurements were made in the field, all values were subsequently transformed to a common horizontal base. To each measurement was added or subtracted a correction value, depending on whether the horizontal AB was above or below the measurement line AC, (Fig. 4.1). If position A is assigned the x_o value on line AC, then x_1, x_2, ... x_n follow at 10 cm intervals, and the correction value for the nth position is $10n \sin \alpha$, where α is the angle BAC. When corrected to a horizontal base therefore, the original measurement x_n becomes $(x_n \pm 10n \sin \alpha)$.

The corrected values can be used to calculate the variance for each transect, which is a measure of the soil microtopography across the trail.

Figure 4.1


Soil microtopography
a. Field measurement
vertical distance measurements
measurement line
survey pin
surface of path
width of path
b. Correction of field measurement to horizontal base
α
10sinα
20sinα
A
B
10cm
10cm
C
x1
x2
x3
X
Y
Z

CHAPTER V

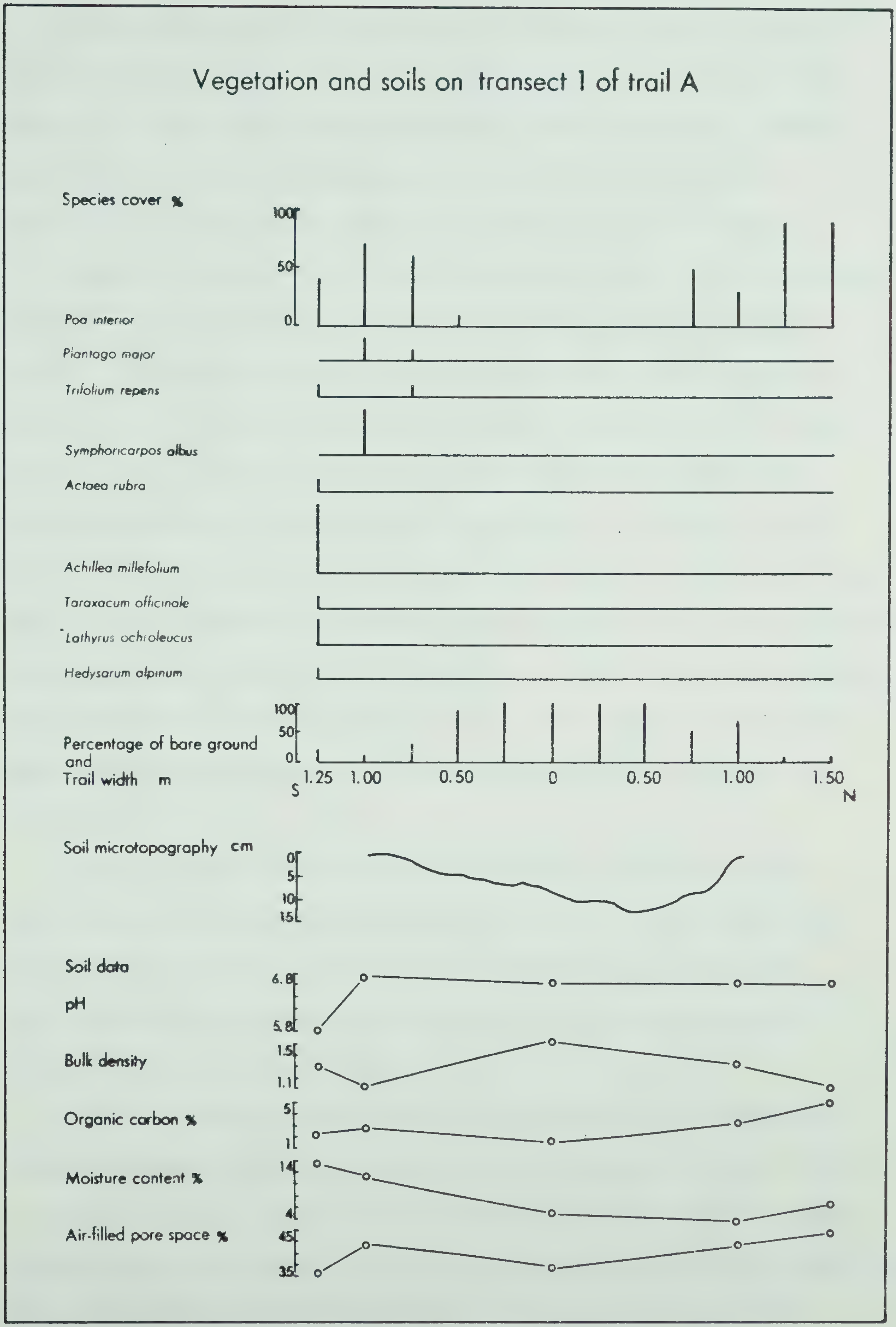
RESULTS

5.1 Introduction

This chapter presents the results of field and laboratory analyses. It is divided into two main sections: the results for each variable studied are considered first followed by the statistical treatments of correlation and regression analysis. The first section (results of individual variables) is divided into three parts for each variable: a discussion of the limitations of the method used, a tabular and graphic presentation of results, and a consideration of the possible effects of that variable on plant growth.

The data for the transects are considered in two ways. First, the trends across individual transects are described as a series of cross-sections of the trail. The results are then examined in five zones parallel to the trail, by using the mean of each zone to obtain an "average" transect. The problem is to reduce a mass of data in such a way that any trend may be readily recognisable, while still acknowledging the inherent variability of soil and plant material. It is possible to plot all the variables determined for one transect, and an example is given of this (Figure 5.1). An interpretation of the individual transects could be attempted in this way. However, it is more useful to examine general trends rather than specific examples; the latter may be of use in accounting for deviations from the general pattern. A major problem with the vegetation analysis was to transform the path width so that transects would be comparable. This is dis-

Figure 5.1


Vegetation and soils on transect 1 of trail A
Species cover %
100
50
0
Poa interior
Plantago major
Trifolium repens
Symphoricarpos albus
Actaea rubra
Achillea millefolium
Taraxacum officinale
Lathyrus ochroleucus
Hedysarum alpinum
Percentage of bare ground and
Trail width m
1.25
1.00
0.50
0
0.50
1.00
1.50
S
N
Soil microtopography cm
0
5
10
15
Soil data
pH
6.8
5.8
Bulk density
1.5
1.1
Organic carbon %
5
1
Moisture content %
14
4
Air-filled pore space %
45
35

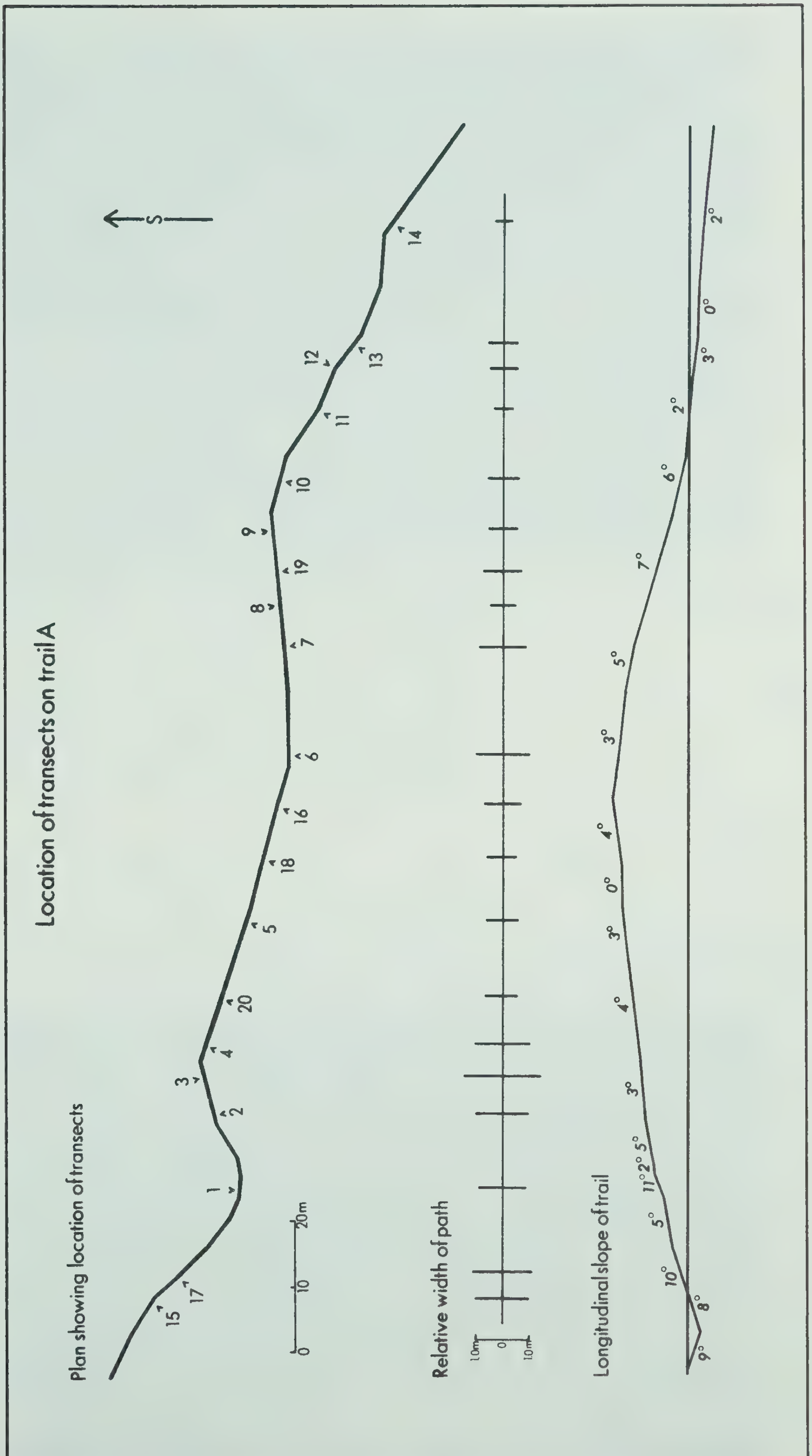
cussed in more detail in the section on vegetation.

Soil texture was not analysed as field observations indicated no obvious textural change along the length of the path, or between the path and its surrounds, which were mainly sandy clay loams. Certain soil properties vary with texture, but the relationships are not sufficiently specific for texture to be used as a guide to them.

Removal of vegetation by trampling exposes the soil to increasing compaction by rainfall as well as additional compactive treading forces. These processes have a detrimental effect on soil aggregate stability. Water-stable aggregate formation is related to the nature of the organic and clay colloid fractions of the soil, and a high aggregate stability is coupled with a resistance to erosion (Black, 1957). The breakdown of soil aggregate by rainfall released the fine soil particles, which are filtered out of the water as it enters the soil and block off the large non-capillary pores. These large pores control the infiltration rate and soil aeration. Their closure by the fine particles thereby reduces infiltration, and runoff and erosion are increased.

Only trail A was examined in great detail, although there are various measurements recorded on trails B and C. A plan of trail A (Figure 5.2) shows the location of the twenty detailed transects, and Plates 5.1-5.10 illustrate the general site conditions as well as specific points of interest.

The five sampling points representing the five trail zones are referred to and appear in the tables as the following initials: trail A - N,N/2,C,S/2,S; trail C - W,W/2,C,E/2,E. In both cases 'C' refers to the centre of the trail. As trail A runs approximately east-west, the sides of the path are north and south. The edges of the path are



Location of transects on trail A
Plan showing location of transects
S
0
10
20m
Relative width of path
1.0m
0
1.0m
Longitudinal slope of trail

Figure 5.2

Plate 5.1 Transect 1, trail A, looking west. July, 1971.

Plate 5.2 Transect 2, trail A, looking south-west. Note steep shady bank on left of photograph. Sandy mound on right is material washed down from bank and supports mainly *Taraxacum officinale*. July, 1971.

Plate 5.3

Transect 20, trail A looking west. Note washout on path behind transect line. July, 1971.

Plate 5.4

Close-up of washout by transect 20, trail A. Note snow accumulation in hollow. April, 1971.

Plate 5.5 Transect 16, trail A, looking west. Slope has an eastern aspect. There are desiccation cracks on the path and the rut in the centre was made by a trail bike under moist soil conditions. Note growth of *Phleum pratense* on south (left) side of path. July, 1971.

Plate 5.6 Transect 18, trail A, looking west. Note desiccation cracks on path and variable shading. *Trifolium repens* has established on south (left) edge of path only. July, 1971.

Plate 5.7 Transect 19, trail A, looking west. Slope has western aspect; note shading on south (left) side. Rut in path made by trail bike. July, 1971.

Plate 5.8 Photograph taken below Transect 19, trail A, looking upslope in an easterly direction. Moose (*Alces alces*) droppings in the foreground indicate that the trail is used by wildlife probably to a greater extent in winter than in the tourist seasons. April, 1971.

Plate 5.9 Transect 15, trail A, eastern aspect and looking west to transects 17 and 1. Rut caused by trail bikes. July, 1971.

Plate 5.10 Looking east towards transects 16 and 18, Trail A. April, 1971.

therefore designated as the appropriate direction with the addition of '/2' as they are the point of 50% bare ground. The edge of the path on the north side therefore is written as N/2, and that of the south side as S/2. The north and south ends of the transect are distinguished by the direction initial only; the north end appears as N, and the south end as S. The zones of trail C are named in a similar manner, but as this trail runs north-south the zones are labelled with east and west initials.

The majority of species were identified in the field; verification and identification of the remainder was done by Miss M. Dumais at the University of Alberta Herbarium.

5.2 Results

5.2.1 Soil Acidity

i. Limitations of the method

The influence of different soil:water ratios on the measured pH has been discussed in an earlier section (Chapter IV). The length of time that the sample is kept also affects the measurement, although in which direction is not clear. Bowser and Leat (1958) recorded the change in pH of a grey wooded soil from two aspen sites in Alberta, after it had been air-dried and stored for three months. Using a 1:1 soil paste they found that samples from one site dropped from 0.5 pH units in the A_0 horizon to 0.2 units in the B_1 horizon; however, an entirely opposite trend was observed for the other site. Furthermore, they monitored soil pH over a period of time and found fluctuations of nearly 2.0 pH units over the growing season. They attributed these fluctuations to variations in the temperature and moisture regime, and suggested a connection with microbiological activity.

The results of this study must be viewed in the light of the above,

as the samples were not only collected over a period of several weeks, but also stored for several months. In addition, only small differences in pH were found. Data from trail C may be regarded with more confidence as they were collected over a shorter period at the end of the field season, so that the storage time was less.

ii. Results

The general hypothesis was that there would be a difference in pH between the trail and its undisturbed surrounds. The Cypress Hills area does not receive a great amount of rainfall (Chapter II), so the base saturation may be expected to be fairly high. If the trail is compacted, a high runoff is predicted along with low infiltration and leaching, and a resultant low opportunity for hydrogen ions to replace metal ions on the exchange complex. In addition, vegetation on the trail is severely reduced and hence the accumulation of hydrogen ions associated with the removal of bases by plants will also be low. For these reasons it was postulated that a higher than normal pH would be found associated with the trail.

The pH of 125 soil samples from trails A and C was measured (Table 5.1) and the data indicate that there is a tendency for a slight increase in pH at the centre of the trail.

Twelve out of 20 (60%) of the transects on trail A had a higher pH at the centre of the trail than that found at either the north or south end of the transect. The pH in the centre was always higher than at least one end of the transect; as the transect ends represent an undisturbed condition, it follows that the disturbance in the centre of the path has given rise to a higher pH.

The change in pH was considered from path centre to path edge, and then to the undisturbed area. On the north side of the trail, the pH

TABLE 5.1 - MEASURED pH OF SOIL SAMPLES, TRAIL A

	Trail A				
Transect Number	N	N/2	C	S/2	S
1	6.6	6.6	6.6	6.7	5.8
2	6.6	6.8	6.2	6.4	5.8
3	6.7	6.6	6.6	6.5	6.3
4	6.2	6.5	6.6	6.1	6.0
5	6.2	6.3	6.7	6.5	6.5
6	6.5	6.6	6.0	6.2	6.0
7	6.3	6.6	6.3	5.7	6.1
8	6.5	6.3	6.7	6.2	6.1
9	6.7	6.8	6.8	6.3	6.3
10	6.9	6.8	6.3	6.4	5.8
11	6.3	6.7	6.6	6.8	6.5
12	6.2	6.7	6.8	6.8	6.4
13	6.4	6.4	6.9	6.7	6.4
14	6.4	6.7	6.9	6.6	6.5
15	6.6	6.6	6.5	6.4	6.2
16	6.4	6.3	6.6	5.8	5.6
17	6.7	6.7	6.6	6.6	6.4
18	6.3	6.4	6.6	6.5	6.5
19	6.8	6.7	6.9	6.3	6.1
20	6.7	6.6	6.8	6.4	5.9
Mean	6.5	6.6	6.6	6.4	6.2
Range	6.2 - 6.9	6.3 - 6.8	6.0 - 6.9	5.7 - 6.8	5.6 - 6.5
Variance	0.04	0.03	0.06	0.08	0.07
Standard Deviation	0.20	0.16	0.25	0.29	0.27

Mean pH and percentage organic carbon of path zones

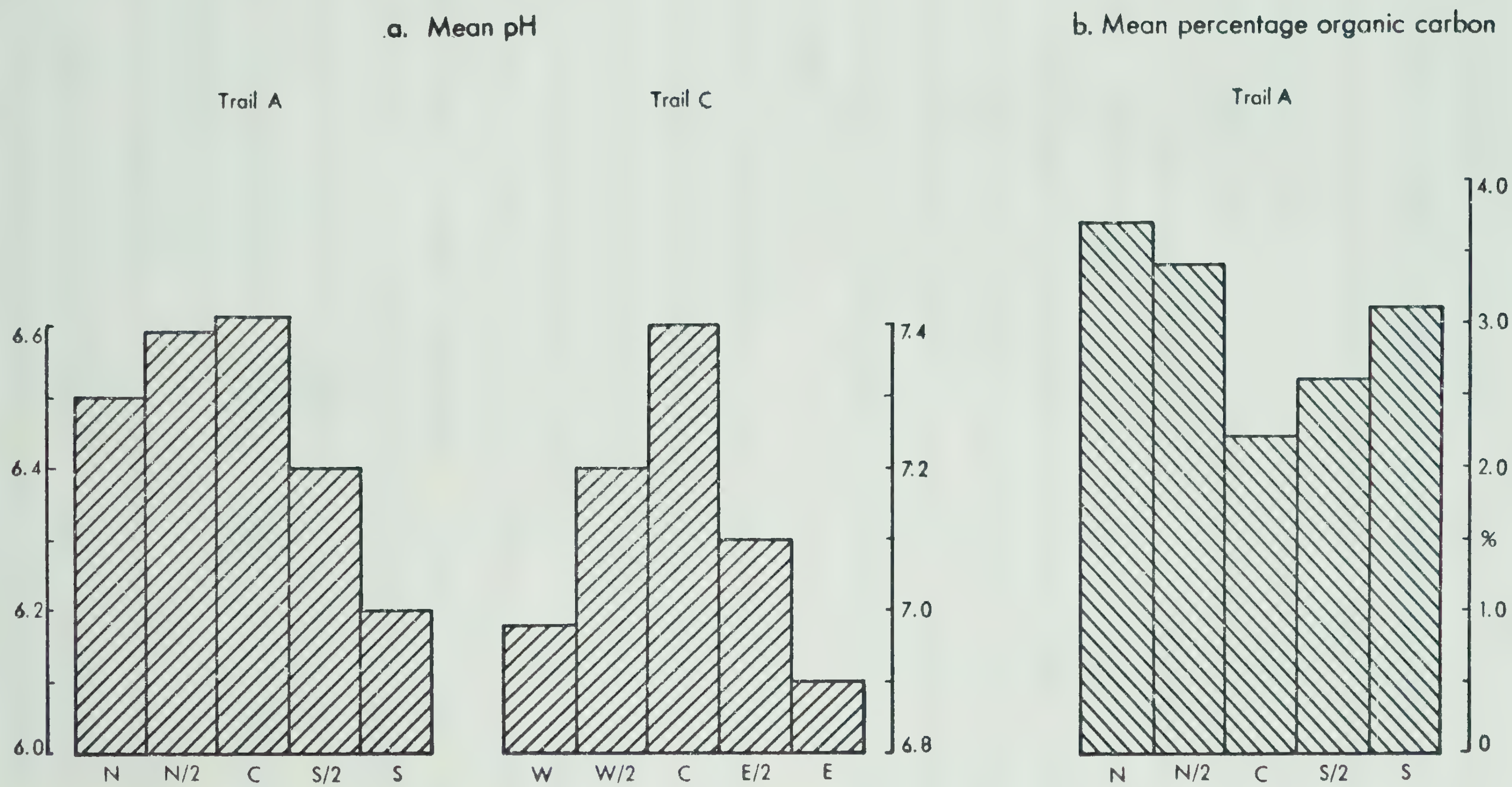


Figure 5.3

at the path edge was found to be less than those found at the centre and in the undisturbed area on as many occasions (four, or 20%) as it was found to be greater. On the south side of the trail however, there was a greater incidence of higher pH at the path edge; lower pH was recorded for only one transect, compared to five where the pH at the edge was greater than both the pH at the centre and in the undisturbed area. When the pH at the centre of the path is compared to the path edges, it is seen that there are more than twice as many transects (nine or 45%) having a greater pH than both edges, than there are transects having a pH lower than both edges (four or 20%). This comparison of path centre to path edge indicates that, although the individual transects vary, there is an overall trend to increased pH in the path centre, and on occasions an increase at the path edge on the south side.

The mean pH for each path zone is shown graphically in Figure 5.3a, and also in Table 5.1. The values for the north side of the trail have a narrower range than those for the south side. The standard deviation of each zone shows that the north edge of the path has the set of values most clustered about the mean, and the north transect end has the next lowest standard deviation. The centre, south edge, and south end of the transect all have more widespread distributions. The increase in pH at the centre of the trail is clearly shown, although much smaller differences are found on the north side of the trail than are found on the south side.

The first four transects of trail C show an increase in pH towards the centre, although the fifth one follows a less regular pattern (Table 5.2). The differences across this path are more pronounced than those encountered on trail A, the latter site having an overall lower

TABLE 5.2 - MEASURED pH OF SOIL SAMPLES, TRAIL C

Trail C					
Transect Number	W	W/2	C	E/2	E
1	7.4	7.7	7.8	7.8	7.5
2	7.6	7.9	8.1	7.7	7.4
3	7.1	7.2	7.8	7.6	7.4
4	6.7	7.1	7.4	6.7	6.2
5	6.0	5.8	6.0	5.7	5.9
Mean	7.0	7.2	7.4	7.1	6.9
Range	6.0-7.6	5.8-7.9	6.0-8.1	5.7-7.8	5.9-7.5
Variance	0.33	0.52	0.60	0.65	0.46
Standard Deviation	0.58	0.72	0.77	0.80	0.68

TABLE 5.3 - BULK DENSITY DETERMINED FROM SOIL CORES (Db), TRAIL C

Trail C					
Transect Number	W	W/2	C	E/2	E
1	1.01	1.30	1.64	1.33	1.06
2	1.30	1.47	1.58	1.24	1.10
3	0.89	1.31	1.62	1.18	1.07
4	0.60	1.03	1.49	0.73	0.61
5	1.04	1.38	1.29	1.20	0.60
Mean	0.97	1.30	1.52	1.14	0.89
Range	0.60-1.30	1.03-1.47	1.29-1.64	0.73-1.33	0.60-1.10
Variance	0.05	0.02	0.02	0.04	0.05
Standard Deviation	0.22	0.15	0.13	0.21	0.23

pH. The mean pH for the zones of trail C are shown graphically in Figure 5.3a, the greater rate of decrease of pH away from the centre of the path being found on the east side.

iii. Effects of pH on plant growth

The data confirm that there is a tendency for pH to increase toward the centre of the trail. The effects of varying degrees of soil acidity on the growth of plants are fourfold.

a. Toxic substances. Toxic acids may accumulate in low pH environments. More important to the higher pH that is found along the centre of trails, is the solubility of aluminium. Aluminium is found as a cation at pH 4.8 - 5.0 and may complex with phosphorus; it is precipitated as the hydroxide between pH 4.8 - 5.0 and 7.5 - 8.0. At a pH greater than 7.5, which occurs on several occasions on the trail, it again becomes soluble in the form of aluminate ions. It is improbable that this anion can enter the root, as it would be precipitated as the hydroxide in the acidic environment of the rhizosphere; it must therefore be mobilised and absorbed, or chelated before entering the root (Jones, 1961). Although not toxic at high pH, aluminium interacts with phosphorus and thus may cause phosphorus deficiency in the plant.

b. Nutrient availability. The effects on nutrient availability are more related to high rather than low soil acidity; non-specific effects are the inhibition of root growth, and therefore nutrient and water uptake, in acidic environments. Specific actions are competition for uptake between hydrogen ions and exchange cations.

An interesting observation is that the changes caused by human pressure in species composition of chalk grassland are the same as would occur with increased soil phosphate: *Festuca ovina*[1] and calcicole grasses → *Lolium perenne* dominated sward → *Lolium perenne-Cynosurus*

1. A list of common names is given in Appendix A.

cristatus mixture→ bare soil (Streeter, 1969). The mechanism by which trampling changes the nutrient status of the soil is not understood, but soil acidity may provide a quick indication of change. Burden (1969) also found a slight decrease in soil acidity on a trail comparable with the present study.

c. Microbial activity. This activity affects organic matter decomposition and nitrogen mineralisation. There are insufficient detailed studies relating pH to the effectiveness of microbial action.

d. Different species. Again little is known about the mechanism by which soil acidity affects the growth of different species. The species response to a particular level of soil acidity is often a reaction not to soil acidity per se, but to changes it has promoted in nutrient status.

5.2.2 Organic Carbon

i. Limitations of the method

The method used, dry combustion and gasometric analysis, was quick and accurate; the most time-consuming part of the analysis was grinding the samples to pass a 100-mesh sieve. Once the sieving had been completed, each sample took only five minutes for combustion and measurement of the volume change after absorption. Fifteen samples were duplicated to check the equipment, but differences in results were negligible. This method is therefore to be recommended over the chemical wet oxidation methods, particularly as the sample has to be sieved before analysis whichever method is chosen. However, this method does call for specialised equipment which is not as readily available as the simple glassware required for chemical analysis.

ii. Results

Soil samples from trail A only were analysed. None of these

samples reacted with hydrochloric acid and so it was assumed that no inorganic carbon in the form of carbonates was present. Organic carbon content was therefore taken to be the total carbon content. One hundred samples were analysed and the results are shown for the five sampling zones in each transect (Table 5.4). Samples from the centre of the trail were expected to show lower percentages than those taken elsewhere, because of the lack of vegetation and input from plant litter.

The overall tendency is for a decrease in organic carbon in the centre of the trail compared to the undisturbed zones on either side. Fifteen transects (75%) showed this expected trend. Of the remaining five transects, two showed an inverse relationship, the central carbon percentage being higher than those at either end of the transect. These two transects (A3 and A4) were sited on a wide section of the path, and in addition there was a steep bank on the south side. The method used for defining the path centre and edges may cause some anomalous results, but is hardly likely to account for differences of this magnitude. The edges of the path also have a higher organic carbon content, and it is suggested that organic material may be washed down from the bank and contribute to increasing soil organic carbon on the path. The remaining three transects show a decrease in carbon content from the transect end on the north side to the centre, and then from the centre to the transect end on the south side.

The edges of the path are of particular interest. In nine transects (45%), a steady decrease in organic carbon content is found from the outer end of the transect on the north side, across the path edge, to the centre of the path. In only one case was the carbon content at the path edge less than both the centre and the outer end of the transect.

TABLE 5.4 - PERCENTAGE OF ORGANIC CARBON IN SOIL SAMPLES, TRAIL A

	Trail A				
Transect Number	N	N/2	C	S/2	S
1	4.7	3.0	1.9	2.6	2.1
2	1.5	1.6	1.0	1.3	2.7
3	3.2	5.1	4.9	2.9	2.9
4	3.8	6.1	4.5	5.9	3.0
5	7.3	3.7	2.9	2.1	2.3
6	3.7	3.1	1.8	3.4	7.7
7	3.9	3.0	1.9	2.1	5.4
8	3.9	4.5	1.8	1.4	2.0
9	1.3	1.7	0.9	1.7	1.6
10	1.2	1.7	0.9	1.5	1.5
11	3.4	1.9	1.0	2.0	2.0
12	2.0	1.4	1.0	4.1	2.6
13	2.0	2.9	2.0	1.3	2.1
14	2.0	1.3	1.6	2.1	1.6
15	8.0	5.9	4.4	3.5	4.3
16	3.8	4.8	3.2	2.4	5.2
17	9.3	6.3	2.9	4.1	4.5
18	3.2	4.2	2.6	2.3	1.7
19	3.0	1.5	0.6	2.1	1.1
20	2.8	4.2	2.0	2.3	5.4
Mean	3.7	3.4	2.2	2.6	3.1
Range	1.2 - 9.3	1.3 - 6.3	0.6 - 4.9	1.3 - 5.9	1.1 - 7.7
Variance	4.61	2.68	1.52	1.28	2.86
Standard Deviation	2.15	1.64	1.23	1.13	1.69

The remaining ten transects (50%) showed an increase in the path edge over the path centre and outer end of the transect. Correspondingly, in six cases (30%) a steady decrease in organic carbon content was found from the south end of the transect, across the path edge, to the path centre. For eight transects (40%) the path edge was higher in organic carbon than either the transect end or the path centre; for six transects (30%) it had a lower content. These data indicate that carbon content was increased at the path edge, on either north or south side of the centre equally, on approximately half of the possible occasions, whereas it was decreased with greater frequency on the south side of the path. No explanation for these proportions was found in other variables associated with the transects, such as whether the path had a transverse slope in the same plane or counter to the overall hillslope.

If the trail is considered as a set of parallel zones, the mean percentages of organic carbon content for each zone may be compared (Figure 5.3b). This reveals the overall pattern of organic carbon content as a gradual decrease towards the centre of the trail, although all zones are within the low (2-4%) organic carbon range. Displaying the mean percentages in a graphic form however fails to convey the variability within each zone. This is remedied in Table 5.4, which gives the range, variance and standard deviation in addition to the mean percentage of each zone. This shows that the ranges are decreased towards the centre and that there are carbon percentages in the medium content range (4-10%) in all groups. The standard deviation is a measure of the clustering of values; the south edge and centre of the path show the greatest uniformity of values, whereas the north end of the transect has the most widespread distribution of observations.

iii. Effects of organic carbon on plant growth.

The organic colloid fraction is a site of exchangeable ions and a source for the replenishment of bases to the soil solution. It is therefore of primary importance in supplying nutrients for plant growth, supplementing the clay fraction which also has exchange sites. The major exchangeable bases are calcium, magnesium, sodium and potassium, which are initially released by the weathering of primary minerals. Hydrogen may replace these metal ions during leaching. The exchange cations therefore depend upon the base status of the parent material, the degree of leaching and the nature of the organic cycle (Black, 1957).

In addition to its role in ion-exchange, organic matter has an effect upon the physical structure of the soil. Its density is less than that of the mineral particles, and so tends to decrease the overall density (Vomocil, 1965). The well-developed crumb structure of brown earths with good drainage and soil aeration, may be contrasted in this respect with the blocky or platey structure developing in the low-organic horizons of podsols.

5.2.3 Bulk Density and Related Variables

The variables included in this section are grouped together as they were based on the core samples collected. Any sampling error is therefore reflected in each set of results, and need only be discussed once.

i. Limitations of the method.

The method of collecting a known-volume sample by coring was not satisfactory, although in cooler and more humid seasons it might be expected to operate more adequately. By mid-summer the centre of the trail had become hard and dry, and it was impossible to

take a core without causing disturbance sufficient to affect the accuracy of the sample. In many cases the soil had a granular structure below the dense surface layer and problems arose in digging out the corer without losing any of the soil. There is therefore a disappointing lack of data for the centre of trail A, and some doubt about the accuracy of the results. Although mean central values are shown, it is emphasised that they do not compare with edge and outer values for two reasons: firstly, the mean central value is based on relatively few samples, and secondly, the data are heavily biased. The mean central bulk density would probably have been increased had it been possible to take samples on what appeared to be the most compacted sites. Some data from the rest of the set are also missing and the tables indicate whether they were selected or random samples. A complete set of data was obtained for trail C because the lower clay content prevented the path from baking to the same degree of hardness.

The excavation method of finding bulk density might have proved less prone to error under these field conditions. Despite the disadvantages outlined in the previous chapter, it would have been worthwhile to test it in the field along with the core method.

ii. Results

a. Bulk density. Tables 5.3,5 shows the bulk density of samples from trails A and C. The results are not discussed in great detail because of their unreliable nature. An increase in bulk density from the outer end of the transect to the path edge was observed in 11 out of 16 (62%) cases on the north side of the path, and 11 out of 13 (85%) on the south side. The mean zone bulk densities indicate an increase towards the centre of the trail (Figure 5.4a). For trail A this is likely to

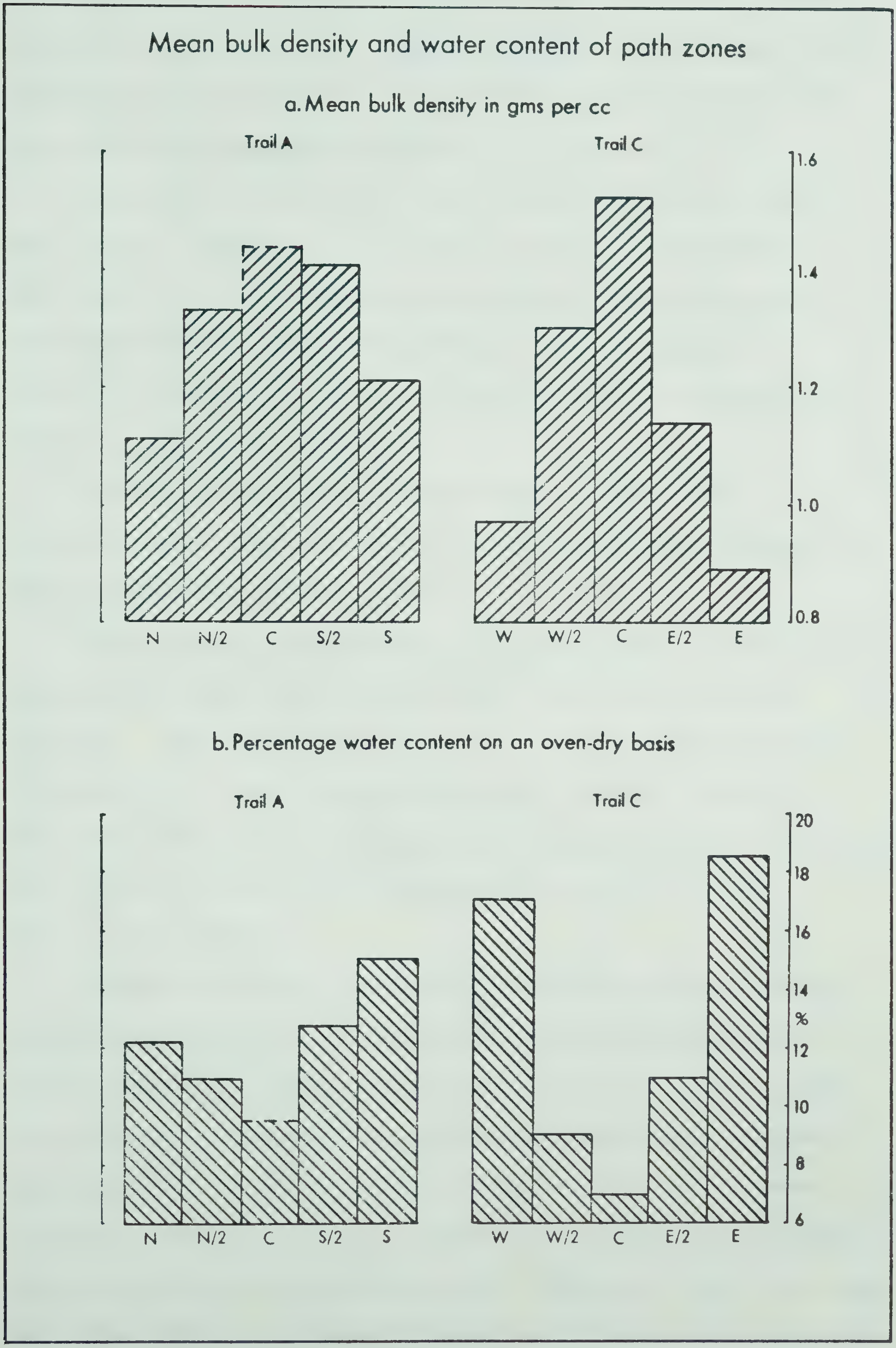
TABLE 5.5 - BULK DENSITY DETERMINED FROM SOIL CORES (Db), TRAIL A

	Trail A				
Transect Number	N	N/2	C	S/2	S
1	1.08	1.27	1.50	1.10	1.27
2	1.70	1.58	1.78	1.36	1.19
3	1.02	0.96	1.10	0.98	1.08
4	1.18	1.15	+	1.30	-
5	0.81	1.20	1.40	1.38	1.24
6	0.99	+	+	+	0.67
7	1.23	1.44	+	1.45	0.91
8	1.30	0.65	+	1.69	-
9	1.16	1.53	+	1.36	1.29
10	1.60	1.48	+	1.54	1.32
11	1.05	1.57	+	+	1.59
12	1.32	1.51	+	1.35	1.29
13	1.10	1.20	+	+	1.44
14	-	1.43	+	1.36	-
15	0.94	1.28	+	1.53	-
16	1.05	-	+	1.52	0.87
17	0.92	1.32	+	1.43	1.29
18	1.18	1.47	+	1.51	1.36
19	1.13	1.53	+	1.68	1.48
20	-	1.37	+	1.50	1.05
Mean	1.15	1.33	1.44	1.41	1.21
Range	0.81 - 1.70	0.65 - 1.65	1.10 - 1.78	0.98 - 1.69	0.67 - 1.59
Variance	0.05	0.05	0.06	0.03	0.05
Standard Deviation	0.22	0.23	0.24	0.18	0.23

\+ soil too compact to sample

\- missing data

Figure 5.4


Mean bulk density and water content of path zones
a. Mean bulk density in gms per cc
Trail A
Trail C
1.6
1.4
1.2
1.0
0.8
N
N/2
C
S/2
S
W
W/2
C
E/2
E
b. Percentage water content on an oven-dry basis
Trail A
Trail C
20
18
16
14
%
12
10
8
6
N
N/2
C
S/2
S
W
W/2
C
E/2
E

be greater than is indicated by the broken line, for reasons already discussed in section 5.2.3i. Trail C shows this increase more clearly. The centre of trail C has the narrowest range of bulk densities and also the smallest standard deviation.

b. Water content. Water content was calculated both on an oven-dry basis and on a volume basis. The oven-dry value is independent of sampling errors, as it is based on the weight of uncombined water in the weighed sample. The volume-based water content however is affected by sampling errors, as the weight of water in the sample is related to the sample volume.

The samples were collected over a period of three weeks, and are therefore of greater use within cross sections rather than zone means, although both are considered.

Table 5.6 shows water content on an oven-dry basis. In most transects on trail A there is a decrease in water content towards the centre. This is reflected in the mean values for the zones shown in Figure 5.4b. There is an even more marked decrease for trail C. The lowest water content of transect C5 is the western edge of the path, and this coincides with the highest bulk density for that transect.(Table 5.7).

The water content on a volume basis (Tables 5.8,9) shows a slightly different picture. Here the volume of water is expressed as a percentage of the total volume of the sample. For trail A, there appears to be a slight increase in volume percentage of water from the ends of the transect to the path edge. This is not found on trail C, where there is a steady decrease to the centre of the trail. If compaction leads to an increase in bulk density and a reduction in total pore space, then water content on a dry-weight basis may be reduced, even though it

TABLE 5.6 - WATER CONTENT ON AN OVEN-DRY WEIGHT BASIS (Pw), TRAIL A

	Trail A				
Transect Number	N	N/2	C	S/2	S
1	5.9	3.6	4.2	10.6	13.3
2	4.7	3.7	3.8	9.9	5.5
3	7.8	16.4	20.2	7.3	3.9
4	20.2	27.7	+	22.9	-
5	11.4	13.6	9.81	10.4	17.0
6	18.7	+	+	+	32.1
7	15.0	10.7	+	17.1	25.1
8	11.4	14.6	+	14.7	-
9	7.7	15.2	+	12.1	10.9
10	5.9	4.2	+	14.6	19.9
11	10.9	6.4	+	+	15.6
12	6.9	7.9	+	6.0	13.7
13	17.2	14.5	+	+	13.2
14	-	6.7	+	11.6	-
15	24.0	19.7	+	20.2	-
16	14.0	-	+	17.9	20.8
17	18.1	16.5	+	20.1	9.8
18	11.3	10.4	+	11.6	15.9
19	7.9	5.1	+	7.7	7.5
20	-	12.0	+	0.4	15.2
Mean	12.2	11.0	9.5	12.7	15.0
Range	4.7 - 24.0	3.6 - 27.7	3.8 - 20.2	0.4 - 22.9	3.9 - 32.1
Variance	30.20	39.99	43.80	31.81	48.69
Standard Deviation	5.49	6.32	6.62	5.64	6.98

\+ soil too compact to sample

\- missing data

TABLE 5.7 - WATER CONTENT ON AN OVEN-DRY WEIGHT BASIS (Pw), TRAIL C

	Trail C				
Transect Number	W	W/2	C	E/2	E
1	17.9	9.3	3.4	9.1	16.0
2	7.3	5.9	4.0	4.7	13.4
3	22.5	10.8	7.5	5.5	11.0
4	25.3	11.6	7.7	25.2	23.9
5	12.7	7.8	11.8	10.3	28.4
Mean	17.1	9.1	6.9	11.0	18.5
Range	7.3-25.3	5.9-11.6	3.4-11.8	4.7-25.2	11.0-28.4
Variance	42.50	4.16	8.93	55.25	43.32
Standard Deviation	6.52	2.04	2.99	7.43	6.58

TABLE 5.8 - WATER CONTENT ON A VOLUME BASIS (Pv), TRAIL C

	Trail C				
Transect Number	W	W/2	C	E/2	E
1	18.08	12.06	5.66	12.05	16.96
2	9.45	8.66	6.40	5.79	14.76
3	20.06	14.12	12.14	6.51	11.74
4	15.16	11.90	11.49	18.40	14.59
5	13.26	10.78	15.17	12.36	17.06
Mean	15.20	11.50	10.17	11.02	15.02
Range	9.45-20.06	8.66-14.12	5.66-15.17	5.79-18.40	11.74-17.06
Variance	13.74	3.18	13.03	20.99	3.78
Standard Deviation	3.70	1.78	3.61	4.58	1.94
% water in total pore vol.	23.9	22.5	24.0	19.6	22.5

TABLE 5.9 - WATER CONTENT ON A VOLUME BASIS (Pv), TRAIL A

	Trail A				
Transect Number	N	N/2	C	S/2	S
1	6.42	4.57	6.30	11.64	16.83
2	8.01	5.91	6.69	13.45	6.42
3	7.93	15.71	22.20	7.16	4.23
4	23.84	31.82	+	29.73	-
5	9.20	16.26	13.73	14.42	21.08
6	18.56	+	+	+	21.49
7	18.50	15.42	+	24.85	22.89
8	14.87	9.50	+	24.86	-
9	8.92	7.89	+	16.42	14.04
10	9.42	6.23	+	22.53	26.28
11	11.41	9.99	+	+	24.79
12	9.17	11.87	+	8.18	17.72
13	18.96	17.40	+	+	19.02
14	-	9.55	+	15.74	-
15	22.60	25.27	+	30.89	-
16	14.67	-	+	27.25	18.11
17	16.67	21.81	+	28.77	12.69
18	13.31	15.33	+	17.46	21.69
19	8.96	7.74	+	12.87	11.07
20	-	16.51	+	0.55	15.94
Mean	13.41	13.82	12.23	18.04	17.14
Range	6.42 - 23.84	4.57 - 25.27	6.30 - 22.20	0.55 - 30.89	4.23 - 26.28
Variance	27.46	49.25	41.87	73.32	36.39
Standard Deviation	5.24	7.01	6.47	8.56	6.03
% water in total pore vol.	23.7	27.7	26.9	38.9	31.4

\+ soil too compact to sample

\- missing data

occupies a greater percentage of the available pore space.

The percentage of pore space occupied by the volume of water is also given in Tables5.8,9. Trail A shows increases in the path edges (Figure 5.5a) over transect ends, but a decrease in the centre. Trail C on the other hand shows decreases at the path ends, and an increase in the centre. A possible explanation for trail A is that compaction has reduced the large-pore volume to a greater extent than capillary pore space has been affected. Although the total pore space is thereby reduced, the proportion capable of retaining water is increased. The path centre however has become very compacted and a breakdown of aggregate structure has released the fine particles which are an integral part of the pore system, so that relatively less water can be retained. The soils of trail C were of a coarser texture, and it is possible that compaction under these conditions has increased the ability to retain water.

c. Total porosity. Total porosity represents the percentage volume of the sample not occupied by soil solids. Data for trails A and C are shown in Tables 5.10,11 and the mean values in Figure 5.5b. This variable is calculated directly from the bulk density using a standard value for particle density. As its distribution is therefore the same as that of bulk density, it will not be commented on beyond the statement that porosity decreases towards the centre of the trail.

d. Air-filled pore space. This is the amount of pore space filled by air as opposed to water, and is shown in Tables 5.12,13. It appears in Figure 5.5b as a fraction of the total porosity. Its percentage volume of total pore space is the remaining percentage up to 100% on the 'percentage volume of water' graph, Figure 5.5a.

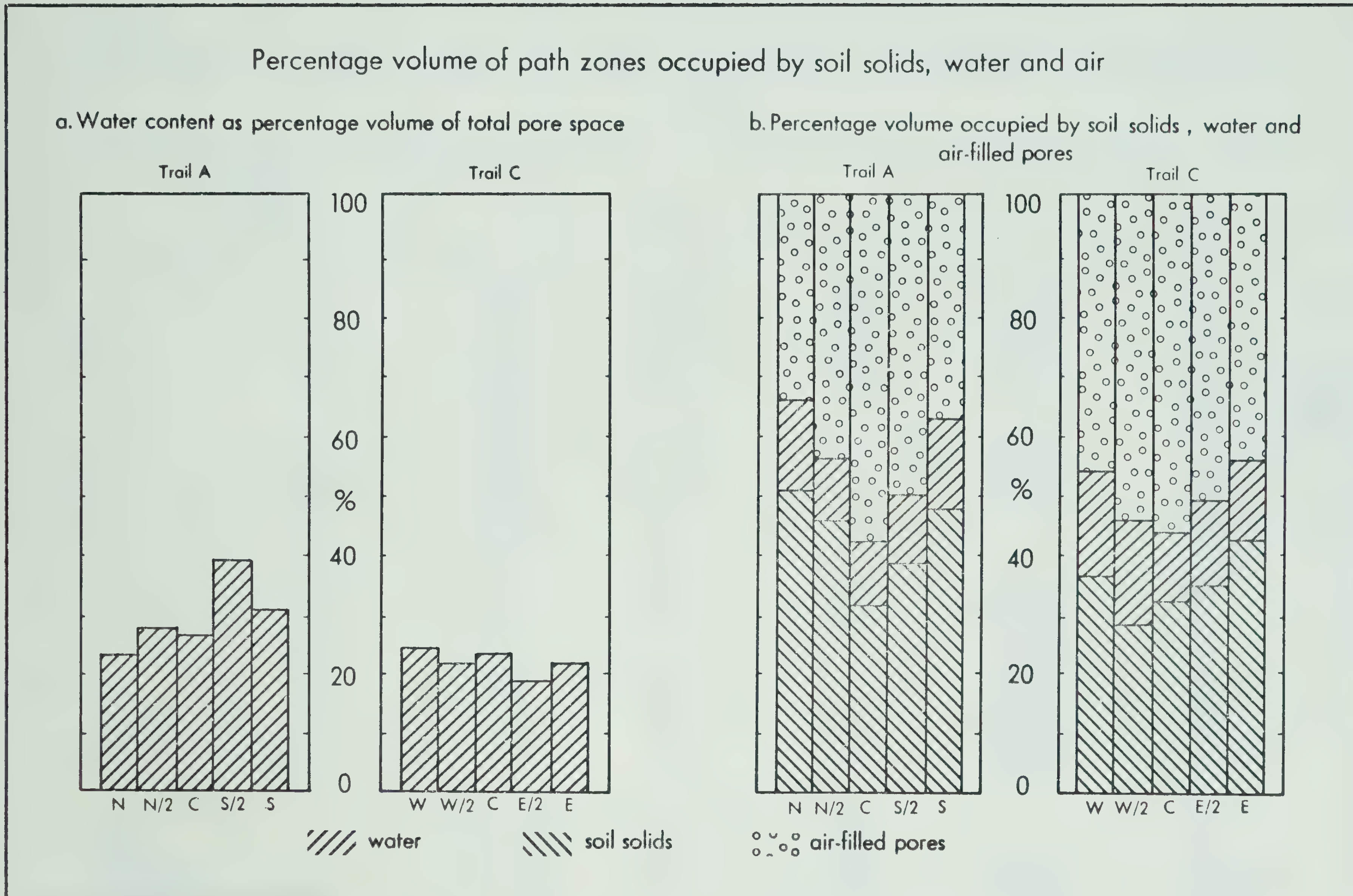

Percentage volume of path zones occupied by soil solids, water and air
a. Water content as percentage volume of total pore space
b. Percentage volume occupied by soil solids , water and air-filled pores
Trail A
Trail C
100
80
60
%
40
20
0
N N/2 C S/2 S
W W/2 C E/2 E
water
soil solids
air-filled pores

Figure 5.5

TABLE 5.10 - TOTAL POROSITY DETERMINED FROM SOIL CORES (St), TRAIL A

	Trail A				
Transect Number	N	N/2	C	S/2	S
1	59.2	52.1	43.4	58.5	52.1
2	35.8	40.4	32.8	48.7	55.1
3	61.5	63.8	58.5	63.0	59.2
4	55.5	56.6	+	50.9	-
5	69.4	54.7	47.2	47.9	53.2
6	62.6	+	+	+	74.7
7	53.6	45.7	+	45.3	65.7
8	50.9	75.5	+	36.2	-
9	56.2	42.3	+	48.7	51.3
10	39.6	44.1	+	41.9	50.2
11	60.4	40.7	+	+	40.0
12	50.2	43.0	+	49.1	51.3
13	58.5	54.7	+	+	45.7
14	-	46.0	+	48.7	-
15	64.5	51.7	+	42.3	-
16	60.4	-	+	42.6	67.2
17	65.3	50.2	+	46.0	51.3
18	55.5	44.5	+	43.0	48.7
19	57.4	42.3	+	36.6	44.1
20	-	48.3	+	43.4	60.4
Mean	56.5	49.8	45.5	46.6	54.4
Range	35.8 - 69.4	40.4 - 63.8	32.8 - 58.5	36.2 - 58.5	40.0 - 74.7
Variance	67.06	76.74	84.14	43.52	77.35
Standard Deviation	8.19	8.76	9.17	6.60	8.79

+ soil too compact to sample

- missing data

TABLE 5.11 - TOTAL POROSITY DETERMINED FROM SOIL CORES (St), TRAIL C

Trail C					
Transect Number	W	W/2	C	E/2	E
1	61.9	50.9	38.1	49.8	60.0
2	50.9	44.5	40.4	53.2	58.5
3	66.4	50.6	38.9	55.5	59.6
4	77.4	61.1	43.8	72.4	77.0
5	60.7	47.9	51.3	54.7	77.4
Mean	63.5	51.0	42.5	57.1	66.5
Range	50.9-77.4	44.5-61.1	38.1-51.3	49.8-72.4	58.5-77.4
Variance	73.68	30.82	23.26	62.44	76.26
Standard Deviation	8.58	5.55	4.82	7.90	8.73

TABLE 5.12 - AIR-FILLED PORE SPACE DETERMINED FROM SOIL CORES (Sa), TRAIL C

Trail C					
Transect Number	W	W/2	C	E/2	E
1	43.8	38.9	32.4	37.8	43.0
2	41.5	35.9	34.0	47.4	43.7
3	46.3	36.4	26.7	49.0	47.9
4	62.2	49.2	32.3	54.0	62.4
5	47.5	37.1	36.1	42.4	60.3
Mean	48.3	39.5	32.3	46.1	51.5
Range	41.5-62.2	35.9-49.2	26.7-36.1	37.8-54.0	43.0-62.4
Variance	52.84	24.61	9.73	31.33	68.18
Standard Deviation	7.27	4.96	3.12	5.60	8.26

TABLE 5.13 - AIR-FILLED PORE SPACE DETERMINED FROM SOIL CORES (Sa), TRAIL A

	Trail A				
Transect Number	N	N/2	C	S/2	S
1	52.8	47.5	37.1	46.8	35.2
2	27.8	34.5	26.1	35.2	48.6
3	53.6	48.1	36.3	55.9	55.0
4	31.6	24.8	+	21.2	-
5	60.2	38.5	33.4	33.5	32.1
6	44.1	+	+	+	53.2
7	35.1	30.2	+	20.4	42.8
8	36.1	66.0	+	11.4	-
9	47.3	34.4	+	32.3	37.3
10	30.2	37.9	+	19.4	23.9
11	49.0	30.8	+	+	15.2
12	41.0	31.1	+	40.9	33.6
13	39.5	37.3	+	+	26.6
14	-	36.5	+	32.9	-
15	41.9	26.4	+	11.4	-
16	45.7	-	+	15.4	49.1
17	48.6	28.4	+	17.3	38.6
18	42.2	29.2	+	25.6	27.0
19	48.4	34.5	+	23.7	33.1
20	-	31.8	+	42.8	44.4
Mean	43.1	36.0	33.2	28.6	37.3
Range	27.8 - 60.2	24.8 - 66.0	26.1 - 37.1	11.4 - 55.9	15.2 - 55.0
Variance	71.11	89.91	18.69	156.88	117.81
Standard Deviation	8.43	9.48	4.32	12.52	10.85

\+ soil too compact to sample

\- missing data

iii. Effects of bulk density and related variables on plant growth

Raney et al. (1955) recognise two kinds of compaction: induced compaction is caused by a recently applied compacting force such as trampling, and genetic or natural compaction, which, as its name suggests is applied to naturally occurring phenomena such as clay or iron hardpans. Induced compaction, which is considered in this study, is generally restricted to the surface layers of the soil, whereas natural compaction may occur anywhere in the soil profile. Both forms of compaction, and hence increased bulk density, may affect plant growth.

The effects of soil compaction on plant growth are both direct and indirect. A compacted layer has a direct effect on root penetration, whilst the soil aeration and moisture status are indirectly affected. Mechanical impedance to root growth was found by Raney et al. (1955) to occur in finer-textured soils when the bulk density exceeds about 1.4, and in coarser soils when it is greater than about 1.6. A similar study showed that root penetration was prevented at bulk densities of 1.75 for sand and 1.46 - 1.62 for clays (Veihmeyer and Hendrickson, 1948). The effects of mechanical impedance are not easy to demonstrate in the absence of indirect effects, but are indicated by a study which provided for controlled aeration (Tackett and Pearson, 1964). The water content was held constant at a particular matric suction, and as the bulk density was increased above 1.3 it was found that a higher oxygen percentage in the soil atmosphere was required to obtain maximum root growth. Although oxygen was not limited and the water content was sufficient for good plant growth, a decrease in root penetration was observed with an increase in bulk density. This was apparently caused by the resistance to displacement of the soil particles.

The nature of the soil atmosphere also affects plant growth and a reduction in oxygen availability has been suggested as contributing to poor root growth in compacted soils (Gill and Miller, 1956). A concurrent increase in carbon dioxide reduces the uptake of mineral salts and water by roots. Decreased water uptake, and consequent moisture stress in the plant, may also result from a reduction in the root growth rate. Water is taken into the root primarily through the root hair zone and the zone of cell enlargement, and these come into contact with the soil water through root growth.

The moisture content of the soil is affected by bulk density changes. Runoff is increased and infiltration reduced in compacted soils. Lutz (1945) found that the infiltration time required for one litre of water was 20 minutes on trampled sand as opposed to three minutes on untrampled sand. An even greater difference was found for a sandy loam, the trampled soil requiring 86 minutes and the untrampled soil only four minutes. In addition to a reduction in the amount of water penetrating the surface soil, the capacity to retain moisture is altered. A certain amount of compaction of the soil may prove beneficial to plant growth if it results in improved moisture retention (Hyder and Sneva, 1956). It is suggested that this is effected by a reduction in large pore space rather than a destruction of aggregates. However, this conclusion was based on a range land study involving bulk densities of 1.05 - 1.21. These are low values compared with those found in a channelled treading situation where bulk densities of 1.5 - 1.8 are not uncommon.

One of the management problems currently receiving attention is that of revegetating recreation sites. The success of reseeding will be affected by degree of soil compaction. Germination and seedling

establishment are phases in the life cycle of a plant when it is very vulnerable to environmental conditions. Germination is initiated by imbibition of water, which increases the permeability of the seed coat to oxygen and carbon dioxide, and activates the enzyme systems. The availability of water is hence of prime importance. A major factor in germination is thought to be the matric potential, by influencing the water uptake and the wetted area of contact between the seed and soil (Collis-George and Hector, 1966). Given reasonable conditions for germination in terms of light, oxygen, temperature and moisture, the effect of compaction may be more limiting to growth when the seedling has become independent of food stores (in the endosperm or cotyledons) and photosynthesis alone has to meet its energy requirements.

A simple germination experiment, which examined the performance of seeds on soils of different compaction, was conducted as part of this study. Seeds of *Festuca rubra* and *Poa pratensis* from a commercial source, and locally-gathered *Plantago major* were sown on greenhouse soil. The soil was compacted to bulk densities of 1.25, 1.50 and 1.75 in three greenhouse flats, which were placed in a shallow try of water. Approximately 10 days after sowing, the greatest percentage of germination was on the most compacted soil and probably resulted from an increase in available water, although the seedlings were markedly smaller than those grown on the least compacted soil. By the 18th day the roots of the grass seedlings on the most compacted soil had extended over the soil surface and the root hairs were beginning to turn brown. All species on the compacted soil showed a reduction in growth and vigour. At the end of the experimental period (8 weeks) *Festuca rubra* and *Poa pratensis* on the least compacted soil had grown to approximately twice the height of those on bulk densities of 1.50 and 1.75. Those

on the most compacted soil had experienced greater seedling mortality in addition to a reduction in growth; there was also a marked browning of the tips and edges of the leaf blades. *Plantago major* appeared to be less affected than the grasses by the different degrees of compaction. An increase in compaction therefore appears to favour rapid germination but is detrimental to subsequent seedling success.

The effect of compaction on plant growth may vary from beneficial to prohibitive. The individual variables concerned are difficult to isolate because of their inter-dependence. The overall effect of the degree of compaction common to recreation sites is detrimental to the re-establishment of plant cover.

5.2.4 Soil Microtopography

i. Limitations of the method

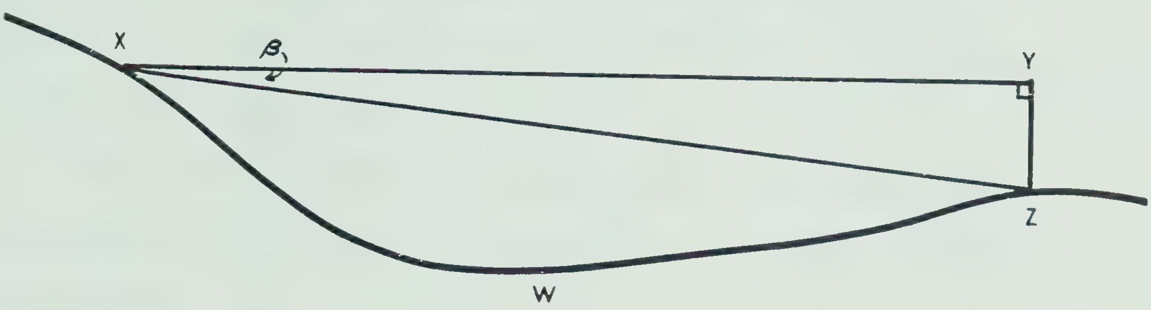
All vertical measurements were corrected to a horizontal base as described. The variance for the corrected set of measurements for each transect was calculated and is shown in the 'total variance' column of Table 5.14. This total variance has two components, the slope factor and the microtopographical, or roughness, factor. The slope factor is the variance that arises if the end vertical measurements of the soil microtopography transect are not equal, i.e. one edge of the path is lower than the other. The roughness factor is the difference between the total and slope variances caused by the departure of the soil surface from a plane surface.

The slope factor or slope variance is proportional to the width of the path and the slope of the line joining the two ends of the transect at ground level. It is calculated as follows. First the distance XY (Figure 5.6a) is found. This is the horizontal width of the path, where X and Z are the ends of the microtopography transect. Figure 4.1b also

Figure 5.6

Soil microtopographical variance

a. Calculation of variance



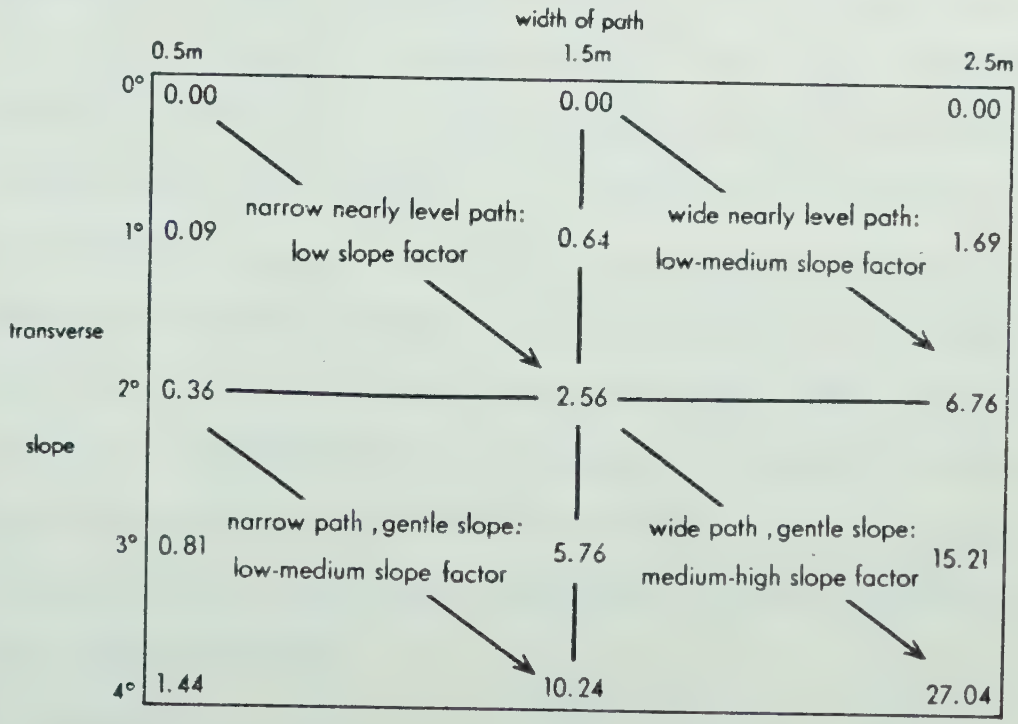
XZ: ends of microtopography transect

XWZ: soil surface

β : slope of XY

b. Relationship between slope, path width and slope factor

Slope factors are shown inside the grid



shows X,Y,Z, and from this it is seen that XY = AB. AB is easily calculated as AC and α, the slope of the transect line, are known. Therefore, XY = AC x Cosine α. YZ, the difference in height at ground level of the ends of the transect, is the difference in the end vertical measurements corrected to the horizontal base, i.e. YZ = BZ - AX. Angle ZXY (β) may now be calculated using tangent β = YZ/XY = BA - AX/AC Cos α.

It was determined that the square root of the slope factor was proportional to the angle β(in degrees) and the number of vertical measurements:

$$\text{slope factor} = \frac{\beta \times \text{no. vertical measurements}^2}{20}$$

If slope is held constant therefore, increasing the length of the transect increases the slope factor. Similarly, with constant width, an increase in slope increases the slope factor. The relationship between slope, width, and slope factor is shown in Figure 5.6b.

Total variance (s_t^2) is represented in Figure 5.6a by the area enclosed by WXYZ. The slope factor (s_s^2) as defined and calculated is represented by the area XYZ. The remaining area WXZ therefore represents the roughness factor (s_m^2) caused by the departure of soil surface XWZ from the straight line XZ, and $s_t^2 = s_s^2 + s_m^2$. If the two ends of the transect are level there is no slope factor, i.e. $s_s^2 = 0$, and $s_t^2 = s_m^2$. Similarly if the path surface is a smooth plane between the two ends, there is no roughness factor, i.e. $s_m^2 = 0$, and $s_t^2 = s_s^2$. Although the condition of zero slope occurs in the field, that of zero roughness does not.

ii. <u>Results</u>

Table 5.14 shows the total variance, slope factor and roughness

TABLE 5.14 - SOIL MICROTOPOGRAPHY ON TRAILS A, B, AND C

	Trail A			Trail B		
Transect Number	Total variance	Slope factor	Roughness factor	Total variance	Slope factor	Roughness factor
1	11.7	0.3	11.4	1.5	0.5	1.0
2	10.4	4.2	6.2	1.8	0.5	1.3
3	519.0	541.6	-22.6*	1.6	2.2	-0.6*
4	18.7	14.3	4.4	3.7	0.6	3.1
5	10.2	6.7	3.5	4.5	0.1	4.4
6	19.3	2.8	16.5	5.6	2.3	3.3
7	22.8	1.7	21.1	2.7	0.0	2.7
8	49.7	0.2	49.5	2.7	0.1	2.6
9	24.6	0.1	24.5	-	-	-
10	54.1	21.3	32.8	2.8	0.7	2.1
11	6.2	0.3	5.9	2.1	0.0	2.1
12	8.0	2.4	5.6	1.5	0.0	1.6
13	0.6	1.0	-0.4*	0.8	0.2	0.6
14	1.4	0.3	1.1	2.3	0.4	1.9
15	11.4	4.4	7.0	3.2	0.0	3.2
16	14.3	12.2	2.1	5.4	0.2	5.2
17	19.1	9.3	9.8	6.3	3.2	3.1
18	1.5	0.0	1.5	6.0	0.0	6.0
19	74.3	3.5	70.8	2.2	0.0	2.2
20	21.2	7.3	13.9	3.2	2.6	0.6

	Trail C		
Transect Number	Total variance	Slope factor	Roughness factor
1	20.2	0.3	19.9
2	4.4	2.2	2.2
3	3.0	0.9	2.1
4	9.3	1.0	8.3
5	28.9	0.0	28.9

* see Appendix B for a discussion of negative values

factor, the last being obtained by the subtraction of the slope factor from the total variance. The roughness factor is the mean-square about the mean observation and therefore increases as the distribution of observations becomes more widely spread. There are roughness factors ranging from 70.8 (A19) to 0.6 (B13, B20). The data for the three trails were ranked and put into the following groups: very high (>45), high (45-15), medium (5-15), and low (<5). These groups were chosen on the basis of the spread of the data and are shown in Table 5.15.

Having seen that there are differences in microtopographical variance at points along the trail, the next step is to determine whether there are other characteristics common to the soil roughness groups. It is suggested that the roughness factor is related to:

a. width of the trail

b. slope across the trail (transverse slope)

c. slope parallel to the length of the trail (longitudinal slope)

d. aspect and vegetation.

The inclusion of (c) introduces an extra spatial dimension. The roughness factor covers two dimensions, those of a vertical plane perpendicular to the length of the trail. Although microtopography is conveniently described at a particular point in this manner, its development must be considered in three dimensions. A fourth dimension, not discussed here, is that of time which is also instrumental in the development of the microtopography. The four contributory factors described above are discussed individually:

a. Trail width. A plot of roughness factor against trail width for all transects is shown in Figure B.1, Appendix B. There is no immediately obvious pattern except that trails with the highest roughness factors appear to be of medium width (100-140 cms.), the range of width increasing

TABLE 5.15 - SOIL ROUGHNESS GROUPS, TRAIL A

Trail A				
	Transect Number	Roughness Factor	Longitudinal Angle	Aspect
High roughness factor	19	70.8	7°50'	265°
	8	49.5	7°50'	265°
	10	32.8	6°10'	284°
	9	24.5	7°50'	265°
	7	21.1	7°50'	265°
	6	16.5	2°40'	269°
Medium roughness factor	20	13.9	3°30'	108°
	1	11.4	10°50'	95°
	17	9.8	9°30'	137°
	15	7.0	8°30'	124°
	2	6.2	2°50'	74°
	11	5.9	2°20'	292°
	12	5.6	3°30'	305°
Low roughness factor	4	4.4	3°30'	108°
	5	3.5	3°10'	108°
	16	2.1	4°0'	105°
	18	1.5	4°0'	105°
	14	1.1	2°10'	306°
	13	0.4	3°30'	305°

as the roughness factor decreases.

b. Transverse slope. A plot of the square root of the slope factor against trail width is shown in Figure B.2, Appendix B. As transverse slope is a function of trail width as well as the difference in height between the ends of the transect, the graphs for constant slope were also plotted. A comparison was then made between transects grouped in various ways according to slope (e.g. 0-1°, 1-2°, 2-3°, etc.) and the transects ranked according to the roughness factor. However, no link was found between the angle of transverse slope and the microtopographical variance.

The roughness factor plotted against slope factor shows a more promising relationship (Figure B.3, Appendix B). It appears that as the slope factor increases, the likelihood of finding a low roughness factor decreases. All high and very high roughness factors are found with slope factors less than 4 (with one exception), and all medium roughness factors with slope factors less than 10.

Figure B.3 also shows the breakdown of slope factors into groups. Trail B has not been included as all values occur within the rectangle marked in the lower left corner of the graph and therefore do not have a sufficiently wide range of values. The first totals given are for trail A transects and the figures in parentheses are the totals for trail C. In the first category of a slope factor less than 4, there are more transects in the high roughness factor range than in either medium or low ranges. With a slope factor of 4-10, there are no transects with a high roughness factor, but there are four in the medium and one in the low range. Slope factors greater than 10 were associated with only two transects in the low roughness range. Although high slope factors appear not to be associated with high roughness factors, low slope

factors are found with low, medium and high roughness factors. This suggests that slope factor is not the only discriminating factor in characterising trail roughness, an impression supported by evidence from trail B. On this trail all slope factors were in the low (<4) group. However, of nineteen roughness factors only two were out of the low (<5) group and both by small margins, their values being 5.2 and 6.0. This clustering of values contrasts with the wider distributions of trails A and C. The type of sites of the three trails suggests that longitudinal slope may be responsible for these differences. Trail A, running parallel to the contours of the hillside, might be expected to have higher slope factors than trail B, on the level plateau, or trail C, running at right angles to the contours.

c. Longitudinal slope. The longitudinal slopes are shown for each transect on trail A in Table 5.15. The first five transects in the high roughness range have similar slopes as they were on the same stretch of trail (see Figure 5.2). The sixth member of this group has a much lower slope. The middle roughness group is composed of transects with very high localised slopes (A1, A17, A15), and more shallowly sloped sites. The group of low roughness factors all have longitudinal slopes less than 4°. Steeper slopes are likely therefore to give rise to greater microtopographical variance than shallower slopes, and the departures from this general principle are likely to be accounted for by the influence of aspect on erosion rates.

d. Aspect and vegetation. All transects in the high roughness group deviate only marginally from a direct west aspect (Table 5.15). Transects 2-20 in the medium roughness group all have an easterly or south-easterly aspect. Transect 20 is thought to owe its high roughness variance to its proximity to a wash-out on the trail (Plates 5.3, 5.4). In addition to

the overall downslope movement of material, the lowered area has started to encroach upon the adjacent bare path, which is more susceptible to erosion than the areas stabilised by a ground cover. It is probable that A11 and A12 occur in the medium roughness group because of their western exposure rather than the longitudinal slope. The first four transects in the low roughness group have longitudinal slopes equal to or greater than those of A11 and A12, but this appears to be offset by their eastern aspect. A13 and A14 occur on sites with low slope at the start of a concave stretch of slope.

The section of trail with the eastern aspect is primarily open woodland. At the brow of the hill this gives way to an association of shrubs and grasses, which predominates on the eastern facing slopes. Western slopes are less protected by vegetation from rainfall and snowmelt erosion than the eastern slopes and develop higher roughness factors.

Summary of Results

High microtopographical variance was found to be associated with a medium trail width (100-140 cm.), low slope factor (4°), high longitudinal slope and a western aspect for this particular site. Of these, aspect appears to be more important than longitudinal slope. This is shown by transects in the medium roughness group, which, although having greater longitudinal slopes than those in the high roughness group, possess an eastern aspect. Slope factor may be used as a guide to determine which parts of the trail are likely to develop a high roughness variance, but the factors controlling this development seem to be aspect and longitudinal slope.

iii. Effects of microtopography on plant growth

The primary effect of microtopography is the provision of a range of microenvironments across the trail (Harper et al., 1965).

These offer a variety of microsites to germinating seeds, which are often highly specific in their requirements. At the present time however there are no methods available to measure these microsites at the appropriate scale and only a coarse measurement of microtopography can be made; this has been developed as the roughness factor in this study. This is a measure of the deviation of the path surface from a plane surface. The greater the roughness factor therefore, the greater would be the microenvironmental variability expected in terms of the slope and orientation of the path surface. If increasing the microenvironmental heterogeneity also increases the probability of successful seed germination, one might predict an increased plant cover. It then follows, as the path width was defined in terms of bare ground and hence plant cover, that the highest roughness factors would be found on the narrowest paths; the data showed that this is not necessarily true and other factors must be considered.

There are several contributory factors controlling the plant growth on sections of trail with high roughness factors. Their deeply incised form may offer less opportunity for plant growth on the steep sides. Growth cannot be restricted by trampling in such places, and this was confirmed by the observation that people would either walk along the centre or move out of the lowered channel and walk alongside. The barrenness of steep slopes on either side must therefore be attributable to other causes.

It is suggested that exposure of these sides enables the soil to dry out faster; this is especially significant for the north side of trail A, which becomes orientated in a plane more perpendicular to the sun's rays. The effects of aspect might be

expected to be greater the more deeply incised a section of trail becomes. Furthermore, as high roughness factors develop on relatively steep longitudinal slopes, they are perpetuated by erosion. The seeds of annuals, which are the main path colonisers, may be washed away from the steep sides before germination. This is quite possible as, in addition to erosion during snowmelt, this area receives heavy rainfall in storms occurring mainly in the early summer and autumn.

The results indicate that a multiplier effect is experienced such that the erosion potential of the path is increased due to the lack of plant cover, and an increase in plant cover is impeded by erosion combined with the other factors described.

5.2.5 Vegetation Analysis

Data obtained from transect studies tend to be less easy to handle than many other forms of data, and are often expressed graphically. The axis along which the vegetation characteristic is plotted may be an actual distance scale, such as that used by Kershaw (1958) in a study of pattern in a grassland community. An alternative division of the axis was used by Alvin (1960) in a study of lichen distribution on sand dunes. The axis was divided into zones according to dune age, so that the sequence of species succession could be demonstrated. This latter means of displaying the results would be appropriate to the trail zones, whereas the use of actual distance along the axis is more relevant to the cross-sectional approach.

As with the soils data, the main problem was to reduce the results of the vegetation quadrat analysis into a more general form. It was

felt that the zoning system by which the soil was characterised was not acceptable as it was already based on a consideration of bare ground and plant cover. Distance from the centre of the path was therefore used to plot the changes in plant cover. However, since the width of the path is variable, any general trends in cover tend to be masked by the overlapping of individual trends. The data were therefore arranged such that the points on each transect were coincident where the first vegetation was recorded. These points therefore reflect the average cover most accurately, and the accuracy will decrease with increasing distance. This is because the rate of change of cover is expected to vary between transects. For example, the vegetation associated with a narrow stretch of path generally displays an abrupt transition from a high percentage cover to bare ground. On a wider path the transition is observed to be more gradual.

An ideal solution would be some form of sliding scale based on path width by which the rates of vegetation increase could be made compatible. In the absence of such a transformation, the data were divided into two groups on the basis of the path width. The transects on sections where the trail width was less than 1.5 m were considered together as 'narrow path' group; these were transects 5, 8-14, 16, and 18-20. The remainder were classified as the 'wide path' group.

The percentage cover for the individual species was obtained by totalling the number of "hits" on that particular species at the designated point on the transect, and expressing that total as the percentage of the total number of pins. The distance of the designated point from the centre of the path was taken as the average distance for all the transects in that group. This is clarified by an example: the first point considered is that at which vegetation is first recorded

and in three transects this might occur at 60 cm, 70 cm, and 80 cm from the centre, giving an average distance of 70 cm. Species A might score 8,9 and 10 hits out of a possible total of 30, giving a percentage cover of 90%. Species B might score 2,3, and 4 hits out of a possible 30, giving a percentage cover of 30%. Therefore, 90% for species A and 30% for species B would be plotted at 70 cm from the centre. Bare ground can be calculated as a percentage in the same manner, except that it can never exceed 100% (whereas the total cover of individual species may do so because of overlapping of leaves).

Figure 5.7 was produced for average trail cross-sections using the above method. The upper graph shows percentage of bare ground, total species cover, a cumulative species total, and the number of species present on narrow trails. Total species cover rises to a higher value on the south side of the trail, which was more shaded. From the height of the peak values for the number of species present, there were more species on the south side contributing to total cover than on the north side. The final total number of species is about equal on both sides, as is the final number of species present, and the percentage of bare ground, suggesting that the vegetation has stabilised.

The distribution of individual species contributing to the total cover is shown in Figure 5.8. Those species that are typical and common in the understorey vegetation of aspen stands in the Cypress Hills (Newsome and Dix, 1968) are shown on the lower graph. Species that are frequently found in disturbed habitats are shown on the upper graph. There is a striking difference between the two distributions. The rapidly-growing atypical species tend to peak in their cover up to about 70 cm from the path centre and then decrease in abundance. The typical woodland species have low cover values within this distance and then start to

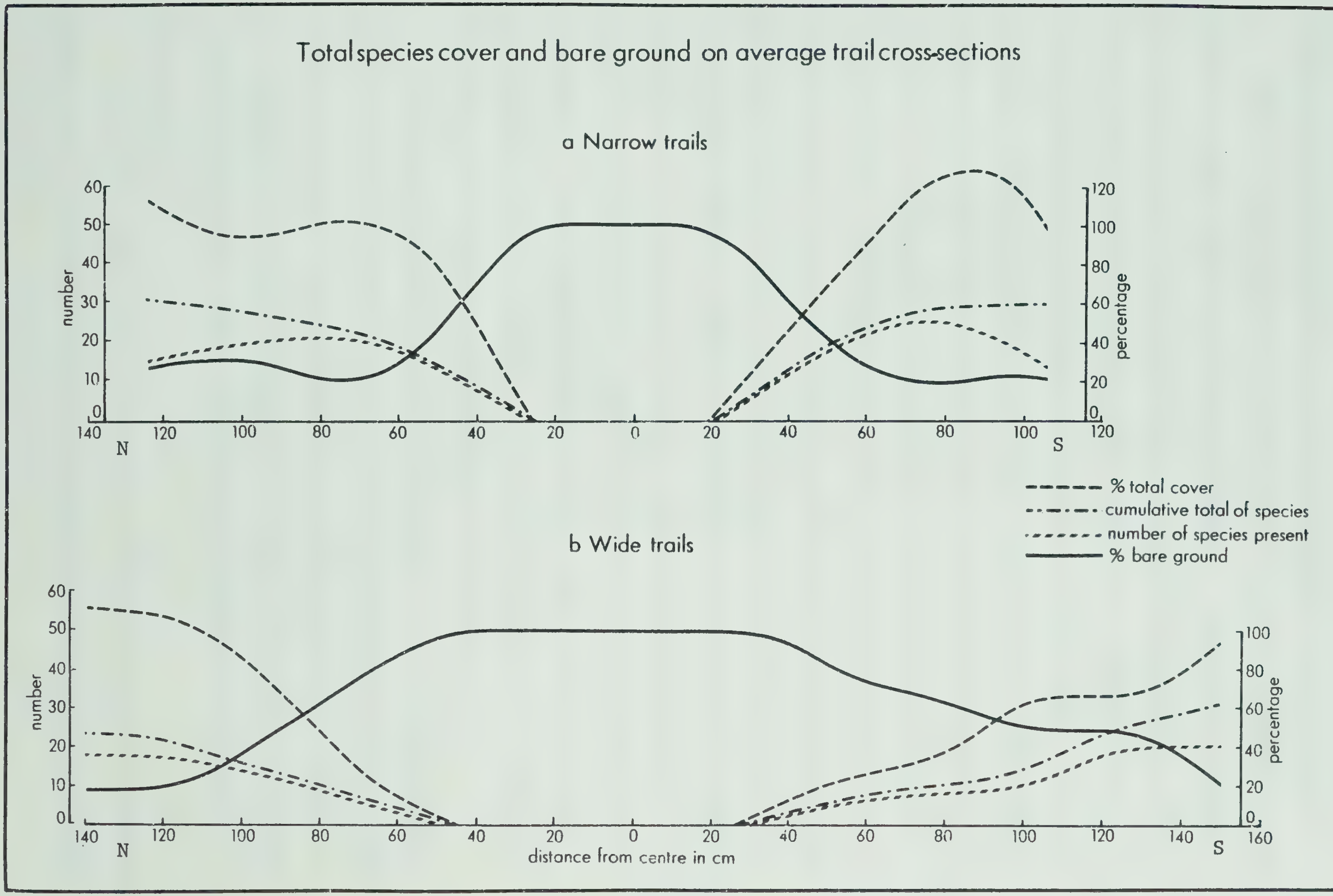

Total species cover and bare ground on average trail cross-sections
a Narrow trails
number
percentage
N
S
% total cover
cumulative total of species
number of species present
% bare ground
b Wide trails
distance from centre in cm

Figure 5.7

increase as the edge species adjacent to the trail edge decrease.

The major edge species that were found in greater abundance near the north edge of the trail were *Poa interior* , *Taraxacum officinale* and *Bromus inermis*. Their abundance was predictably greater on the north side of the path which was less shaded than the south side. Their relationship to one another was altered on the south side, with *Taraxacum officinale* providing the major contribution to total cover although its distribution curve was very similar for both sides of the trail. The abundance of *Poa interior* was very much reduced on the south side, and was exceeded by that of *Trifolium repens*. *Trifolium repens* was most abundant on the shaded (north-facing) side, and comparatively little was recorded on the north side. *Bromus inermis* experienced a change in abundance from the north to the south side similar to that of *Poa interior*. *Bromus inermis* achieved a peak value farther from the centre of the path than the other species considered. *Phleum pratense* was present on both sides of the path, but attained a higher percentage cover on the south side. *Plantago major* was more abundant on the north side of the path.

The typical woodland species do not show the peaked curve common to the atypical or edge species. If they are present near the edge of the path, their rate of increase of percentage cover is very low. The abundance of the woodland species increases more rapidly after the atypical species have peaked and their contribution to total cover declines.

Aster spp. were a major contributor to cover on both the north and south side. On the north side, *Aster* spp. reached a peak at the same

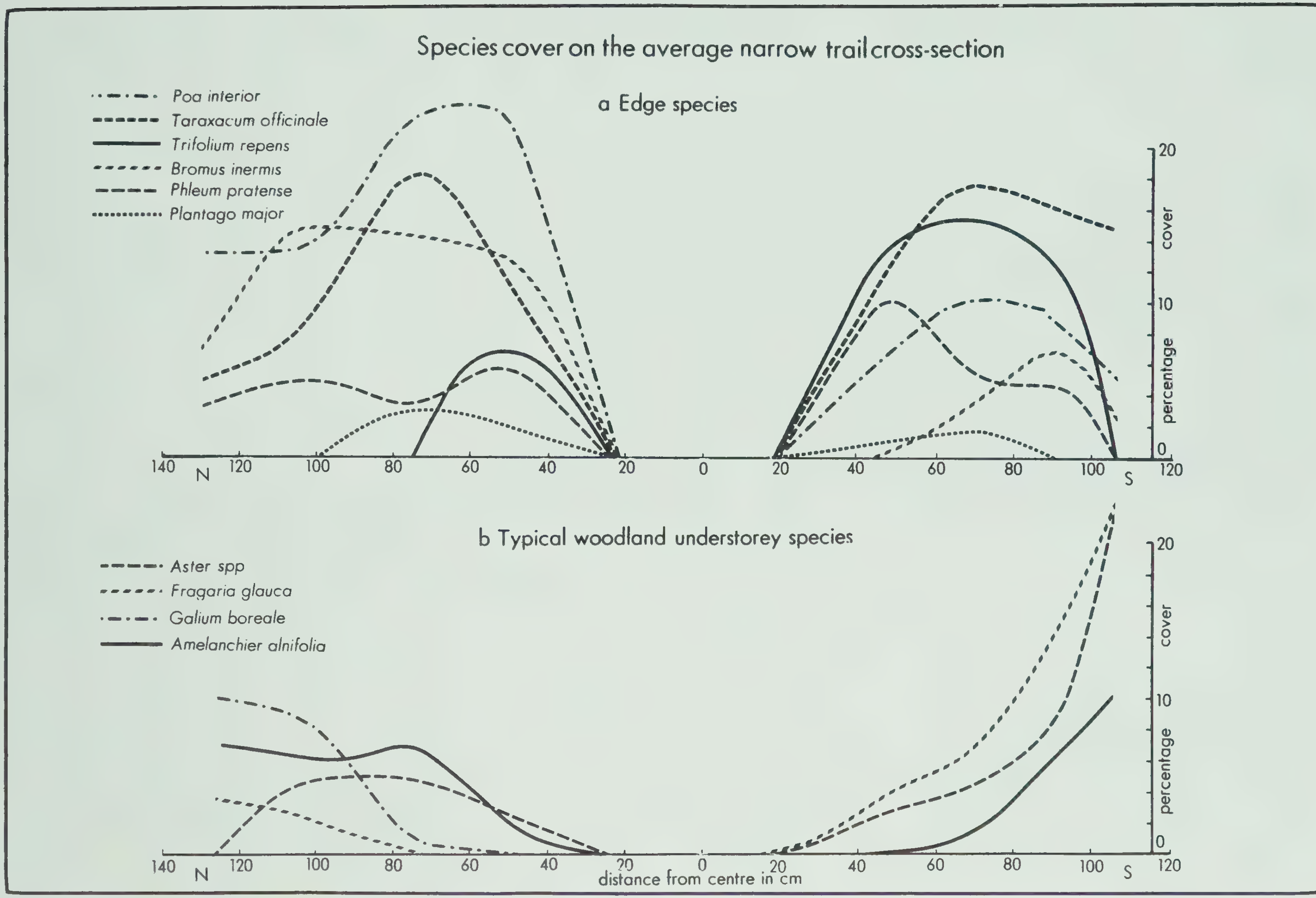
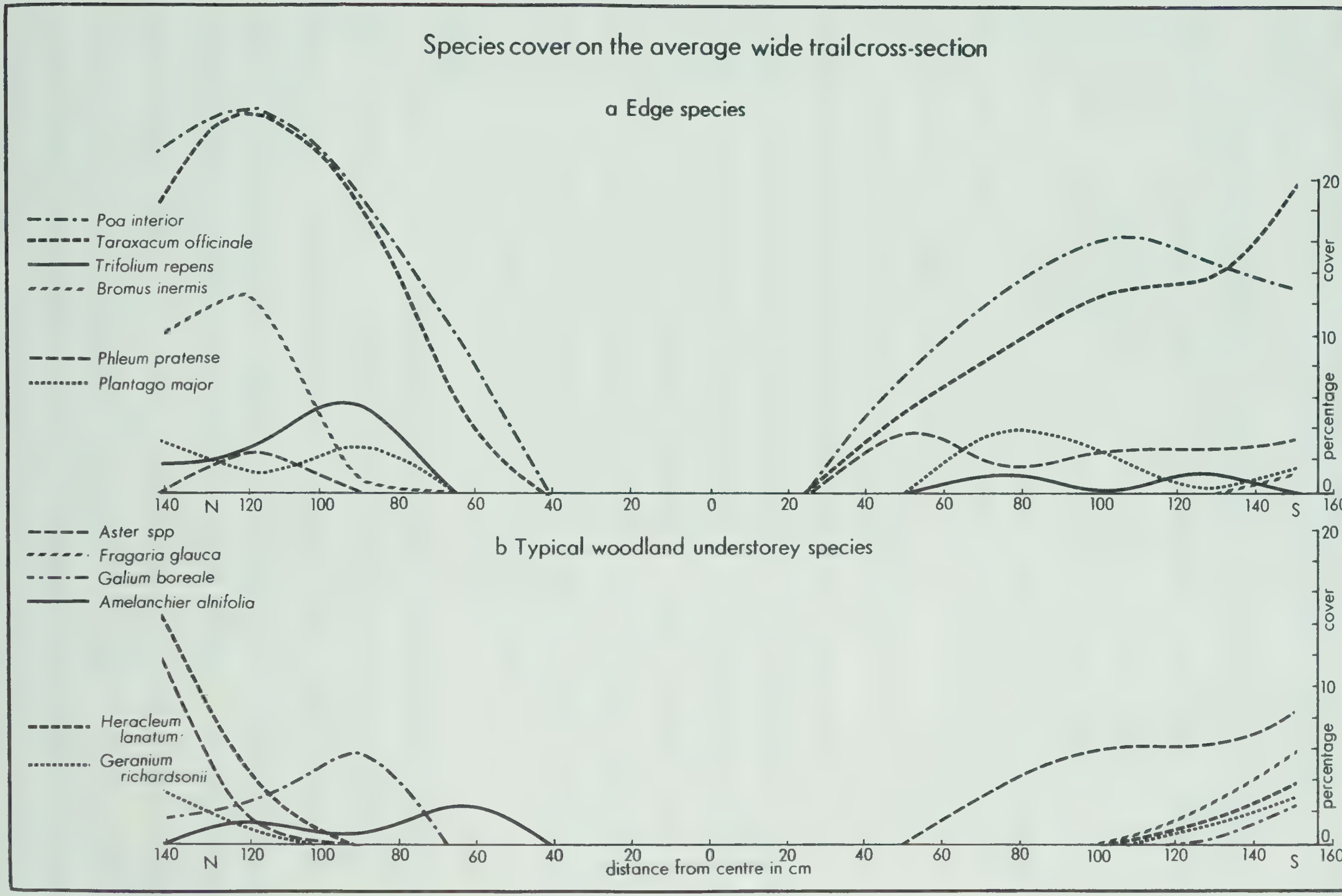

Species cover on the average narrow trail cross-section
a Edge species
Poa interior
Taraxacum officinale
Trifolium repens
Bromus inermis
Phleum pratense
Plantago major
percentage cover
20
10
0
140
N
120
100
80
60
40
20
0
20
40
60
80
100
S
120
b Typical woodland understorey species
Aster spp
Fragaria glauca
Galium boreale
Amelanchier alnifolia
percentage cover
20
10
0
140
N
120
100
80
60
40
20
0
20
40
60
80
100
S
120
distance from centre in cm

Figure 5.8

point as the atypical species and maintained that level of cover up to 100 cm from the trail centre. There was a slower increase in cover on the south side, but a higher final percentage. *Fragaria glauca* was the most abundant species on the south side, although much less successful on the north side. *Amelanchier alnifolia* was present on both sides of the trail and followed the distribution pattern of the other species. *Galium boreale* appeared on the north side immediately following the peak of the atypical species and achieved the highest cover percentage about 100 cm from the trail centre.

The lower graph on Figure 5.7 shows the percentage of bare ground, total species cover, cumulative species total and the number of species present for the wide trails. The north side shows smooth curves with all the variables reaching an equilibrium state without the conspicuous peaking seen on the narrow trails. The south side of the trail is rather different; the curves are attenuated and not smooth, as though they pass through well-vegetated and poorly-vegetated zones. The overall rate of cover increase is much less on this side of the trail, and the bare ground and total cover do not appear to have reached an equilibrium level. The fluctuation in the curves may be partially the effect of a low number of total transects in this group, although the north side of the trail is not affected.

The major edge species for wide trails are shown on the upper graph in Figure 5.9. The abundance of *Taraxacum officinale* and *Poa interior* was again greater on the north side of the path which was less shaded. *Bromus inermis* was restricted to the north side of the path. *Phleum pratense* was present on both sides of the path, although it was more abundant and persisted over a greater distance on the shaded south side. The remaining two major species were *Plantago major*



Species cover on the average wide trail cross-section
a Edge species
Poa interior
Taraxacum officinale
Trifolium repens
Bromus inermis
Phleum pratense
Plantago major
b Typical woodland understorey species
Aster spp
Fragaria glauca
Galium boreale
Amelanchier alnifolia
Heracleum lanatum
Geranium richardsonii
percentage cover
0
10
20
140
N
120
100
80
60
40
20
0
20
40
60
80
100
120
140
S
160
distance from centre in cm

Figure 5.9

and *Trifolium repens*. Both showed greater abundance on the north side of the path.

Of the typical woodland species, the distribution of those to the south of the path was probably less affected by competition from the edge species than those on the north side. *Aster* spp. were most prevalent, occurring nearer the centre and contributing most to the total cover. *Fragaria glauca, Heracleum lanatum, Geranium richardsonii* and *Galium boreale* all appeared over 100 cm away from the centre of the trail and in lesser abundance.

Galium boreale was more abundant on the north of the trail and peaked about 30 cm before the peak of the major edge grasses, at which point its cover was reduced by half. As the abundance of atypical grasses declined, that of *Heracleum lanatum* and *Fragaria glauca* increased abruptly, and that of *Geranium richardsonii* showed a slower increase. Some *Amelanchier alnifolia* was also recorded on the less shaded north side of the trail. It was most abundant just before the increase in abundance of the atypical grasses, and then decreased.

<u>Summary</u>

There are two distinct groups of plants that border the trail. One group consists of species which are typical of disturbed habitats and which exhibit a rapid increase in percentage cover, peak, and then decline in abundance as distance from the centre of the trail increases. These are referred to as the edge or atypical species. The second group of plants found bordering the path are the species typical of the woodland through which the trail passes. These generally have a very low percentage cover until the abundance of the edge species begins to decrease.

The major edge species on this trail were: *Poa interior, Taraxacum officinale, Bromus inermis, Phleum pratense, Plantago major,* and

Trifolium repens. Their abundance was generally greater on the less shaded north side of the path. Typical woodland species that bordered the path were *Fragaria glauca, Aster* spp., *Amelanchier alnifolia, Galium boreale, Geranium richardsonii,* and *Heracleum lanatum.* Species that made a minor contribution to total cover are listed in Table 5.16.

On the narrow trails, the edge species showed maximum cover values at about 70 cm from the trail centre, compared with the peak at 100-120 cm for the wide trails. The division of the trails into two groups based on width is therefore justified; the peaks would have overlapped had this not been done. A further point is that on the narrow trails, the edge species reach a peak over a distance of approximately 50 cm from the first point of vegetation cover; on the wide trail this is extended over about 80 cm. There is a difference therefore not only in the distance from the centre at which maximum cover of edge species occurs, but also in the rate of increase from the first vegetation on the path. Furthermore, both graphs on Figure 5.7 show that although the total cover continues to increase or levels off away from the path, the number of species present reaches a peak and declines. The graphs of individual species cover indicate that the initial rise in the number of species present is accounted for by the edge species, the peak represents edge species and some woodland species, and the decline is accounted for by woodland species.

5.3 Statistical Analysis

5.3.1 Correlation

Correlation techniques are not particularly appropriate to this study, but are included as an example of one possible way to treat the data. The transects were located randomly along the length of the trail, but the five sampling points on the transect were not (stratified random

TABLE 5.16 - SPECIES OF MINOR IMPORTANCE
FOUND ADJACENT TO TRAIL A

Trail A				
Species	Presence			
	Narrow Path		Wide Path	
	North	South	North	South
Agropyron subsecundum	+	+		
Agrostis scabra		+		
Bromus anomalus	+		+	
Poa palustris				
Carex sprengelii	+	+	+	+
Juncus tenuis		+		+
Stellaria longifolia	+			
Actaea rubra				+
Thalictrum venulosum	+		+	
Geum allepicum	+		+	+
Rosa spp.	+	+	+	+
Rubus strigosus	+			
Hedysarum alpinum		+		+
Lathyrus ochroleucus	+	+	+	+
Thermopsis rhombifolia	+	+	+	
Vicia americana	+	+	+	
Lonicera dioica	+	+		
Smilacina stellata	+			+
Disporum trachycarpum	+			+

Table 5.16, Continued

Species	Presence			
	Narrow Path		Wide Path	
	North	South	North	South
Viola rugulosa	+			+
Osmorhiza chilensis		+		
Symphoricarpos albus	+	+	+	+
Campanula rotundifolia				+
Achillea millefolium		+	+	+
Agoseris glauca		+		
Antennaria spp.				+
Artemisia spp.	+		+	
Erigeron spp.	+	+	+	+
Gaillardia aristata				
Hieracium spp.				+
Matricaria matricarioides				+
Solidago spp.	+			
Castilleja miniata		+		+
Spiraea lucida				+

sampling). It is not within the limits of correlation techniques to analyse data which are only partly randomised, and the results must be treated as such. A randomised block sampling treating the path zones as blocks, would be more appropriate to the gathering of data for correlation analysis. If a complete set of data had been obtained for all zones, correlation of variables within each zone would have been possible. As the change in soil variables with bulk density was of prime interest in this study, the lack of data for the central zone of the path unfortunately precluded analysis of the data in this way, and regression analysis is of greater value.

Correlation matrices are given (Table 5.17) for seven variables; distance from the centre of the path is included, but the more reliable data are for the other six variables. A matrix for all data from trail A is given; there are also matrices which treat the north and south sides of the trail separately. As these matrices include the correlation coefficient, its level of significance and the degrees of freedom, these will not be included in the discussion below.

Taking into account all samples from trail A, pH was shown to be negatively correlated with the water content of the soil, although the association is not strong. On the north and south sides of the trail pH shows a weak negative correlation with percentage carbon in addition to water content (oven-dry basis). A positive correlation is shown for the north side of the path between pH and bulk density.

Percentage carbon shows a strong positive correlation with moisture content on a dry weight basis, particularly on the north side of the trail. Its high negative correlation with bulk density is stronger on the south side.

Water content on a dry weight basis has a reasonably strong negative

TABLE 5.17 - CORRELATION MATRICES

Trail A, Totals	Var. 1	Var. 2	Var. 3	Var. 4	Var. 5	Var. 6
Var. 2	-0.325 (100) ***					
Var. 3	0.433 (100) ***	-0.159 (100) N.S.				
Var. 4	0.234 (73) **	-0.370 (73) ***	0.596 (73) ***			
Var. 5	-0.503 (73) ***	0.192 (73) N.S.	-0.676 (73) ***	-0.451 (73) ***		
Var. 6	0.044 (73) N.S.	-0.324 (73) ***	0.319 (73) ***	0.880 (73) ***	-0.041 (73) N.S.	
Var. 7	0.377 (73) ***	0.052 (73) N.S.	0.344 (73) ***	-0.190 (73) *	-0.779 (73) ***	-0.595 (73) ***

*** - significant at 0.01 level of probability
** - significant at 0.05 level of probability
* - significant at 0.10 level of probability

Degrees of freedom are shown in parentheses

Var. 1 distance from centre
Var. 2 pH
Var. 3 percentage carbon
Var. 4 water content (dry weight)
Var. 5 bulk density
Var. 6 water content (by volume)
Var. 7 air filled pore space

Table 5.17, Continued

Trail A, north	Var. 1	Var. 2	Var. 3	Var. 4	Var. 5	Var. 6
Var. 2	-0.095 (60) N.S.					
Var. 3	0.481 (60) ***	-0.224 (60) *				
Var. 4	0.235 (40) N.S.	-0.282 (40) *	0.723 (40) ***			
Var. 5	-0.427 (40) ***	0.329 (40) **	-0.671 (40) ***	-0.601 (40) ***		
Var. 6	0.123 (40) N.S.	-0.209 (40) N.S.	0.585 (40) ***	0.937 (40) ***	-0.325 (40) **	
Var. 7	0.344 (40) ***	-0.185 (40) N.S.	0.281 (40) *	-0.020 (40) N.S.	-0.780 (40) ***	-0.337 (40) **
Trail A, south						
Var. 2	-0.562 (60) ***					
Var. 3	0.430 (60) ***	-0.276 (60) **				
Var. 4	0.268 (37) N.S.	-0.343 (37) **	0.595 (37) ***			
Var. 5	-0.593 (37) ***	0.225 (37) N.S.	-0.706 (37) ***	-0.426 (37) ***		
Var. 6	0.046 (37) N.S.	-0.231 (37) N.S.	0.231 (37) N.S.	0.847 (37) ***	0.045 (37) N.S.	
Var. 7	0.413 (37) **	-0.019 (37) N.S.	0.379 (37) **	-0.221 (37) N.S.	-0.773 (37) ***	-0.668 (37) ***

correlation with bulk density which is greater on the north side.

The strongest correlations are between bulk density and percentage carbon, and bulk density and water content which are negatively associated, and water content and percentage carbon which are positively correlated. It is thus concluded that soils which experience compaction from pedestrian trampling are also likely to exhibit a reduction in moisture content and organic carbon content.

5.3.2 Regression Analysis

Regression analysis requires an independent variable which does not have to be selected randomly. The distance in metres from the centre of the trail was therefore chosen, and equations calculated for the regression of the dependent soil variables on distance.

Regression analysis for total samples from trail A show that percentage carbon, water content on a dry weight basis, and air-filled pore space increase directly with distance from the centre of the path. Percentage carbon (Figure 5.11) has a value of 1.87 at the Y intercept, and the slope of the regression line is 1.41; the equation is significant at the 0.005 level (98 d.f.). Water content (Figure 5.12) has a value of 9.87 at the Y intercept and the slope of the regression line is 2.78; this is significant at the 0.025 level (71 d.f.). Air-filled pore space (Figure 5.14) has a value of 28.65 at the Y intercept and the slope of the regression line is 8.01; the equation is significant at the 0.005 level (71 d.f.).

There is a decrease in pH and bulk density values with distance from the trail centre. Figure 5.10 shows the pH at the Y intercept to be 6.59, and the slope of the regression line is 0.17. The equation is significant at the 0.005 level (98 d.f.). Bulk density (Figure 5.13) regresses on distance from the path centre with a Y intercept of 1.50

Figure 5.10

Regression of pH on distance from the trail centre

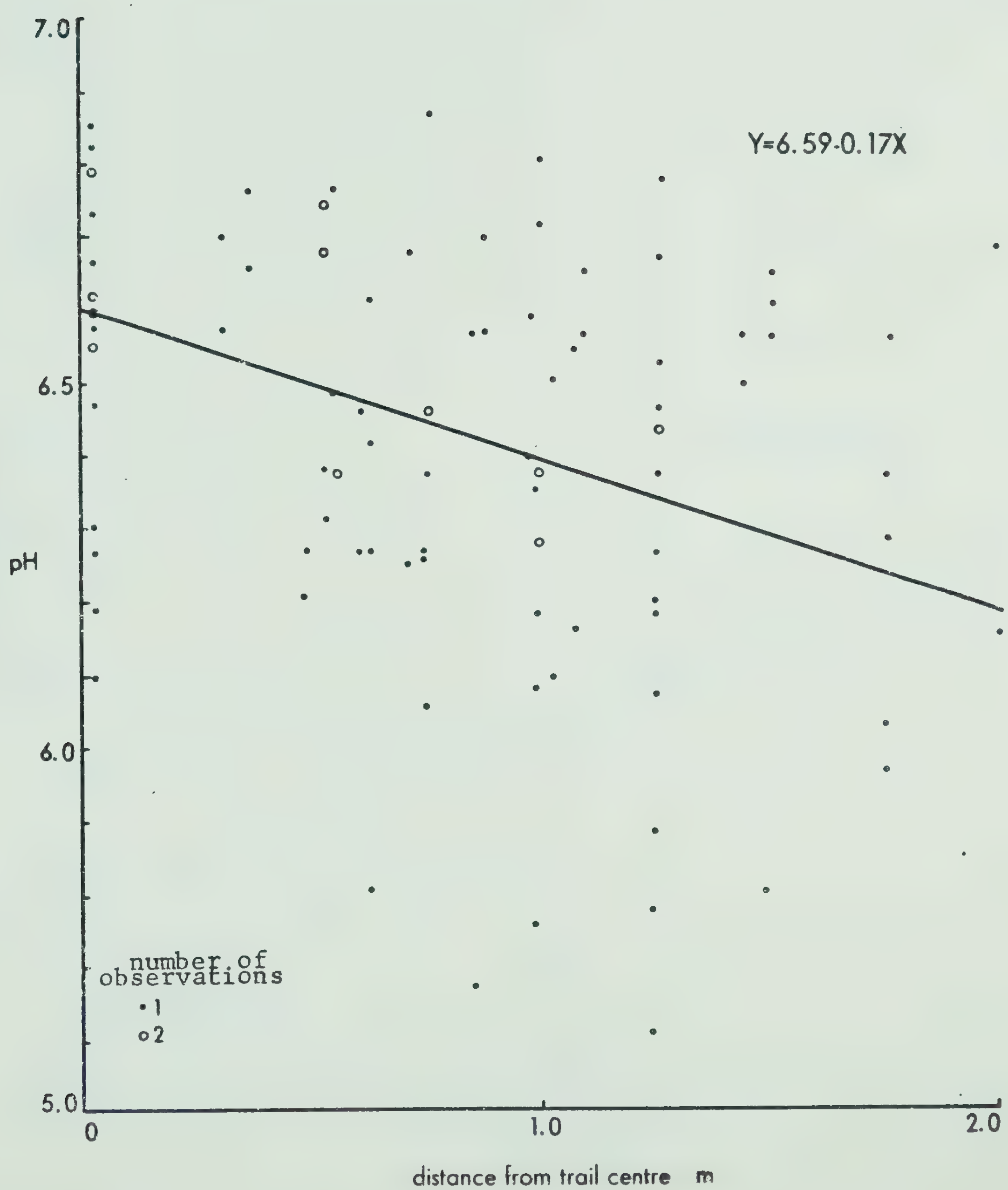


Figure 5.11

Regression of percentage organic carbon on distance from the trail centre

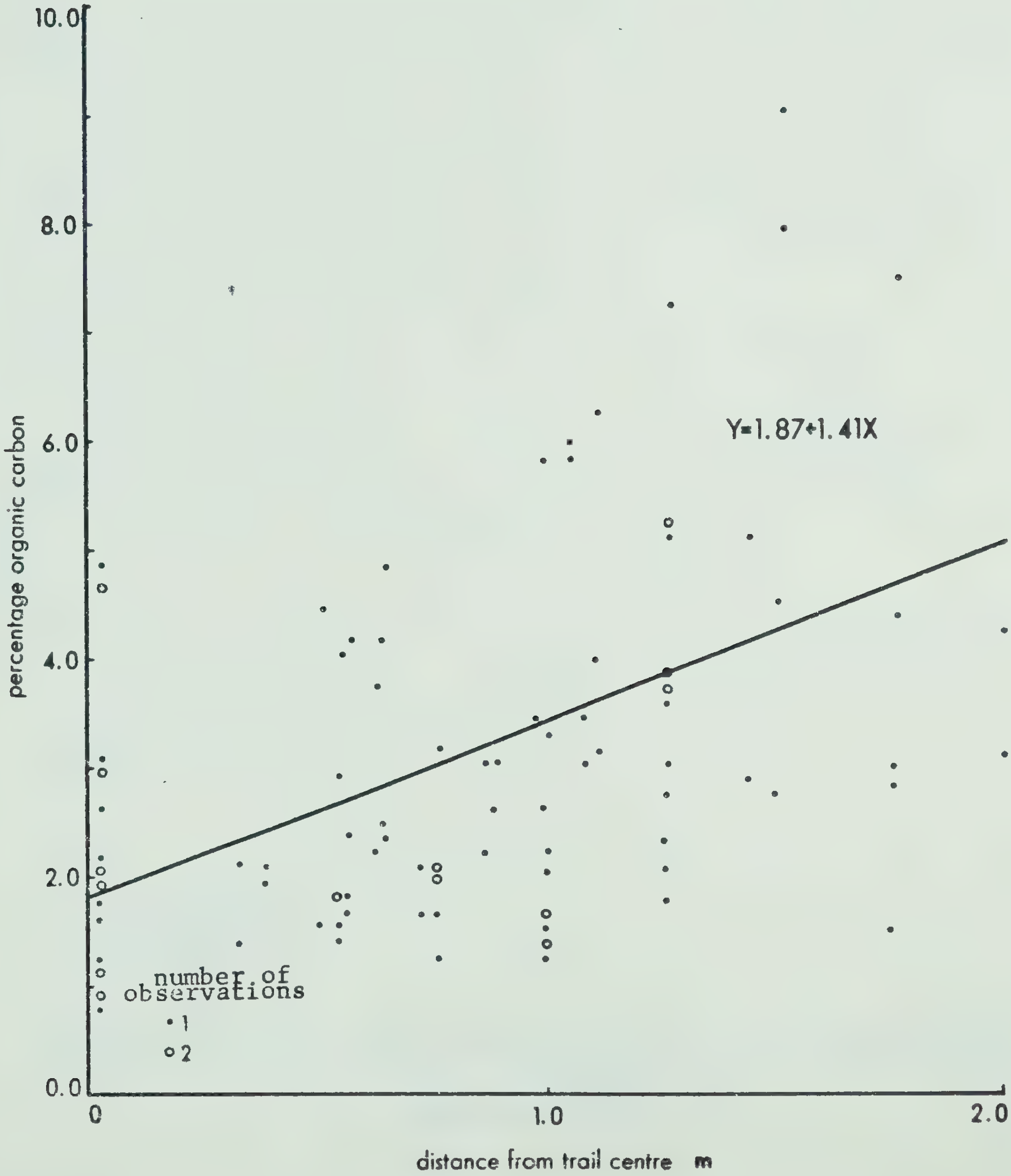


Figure 5.12

Regression of water content on distance from the trail centre

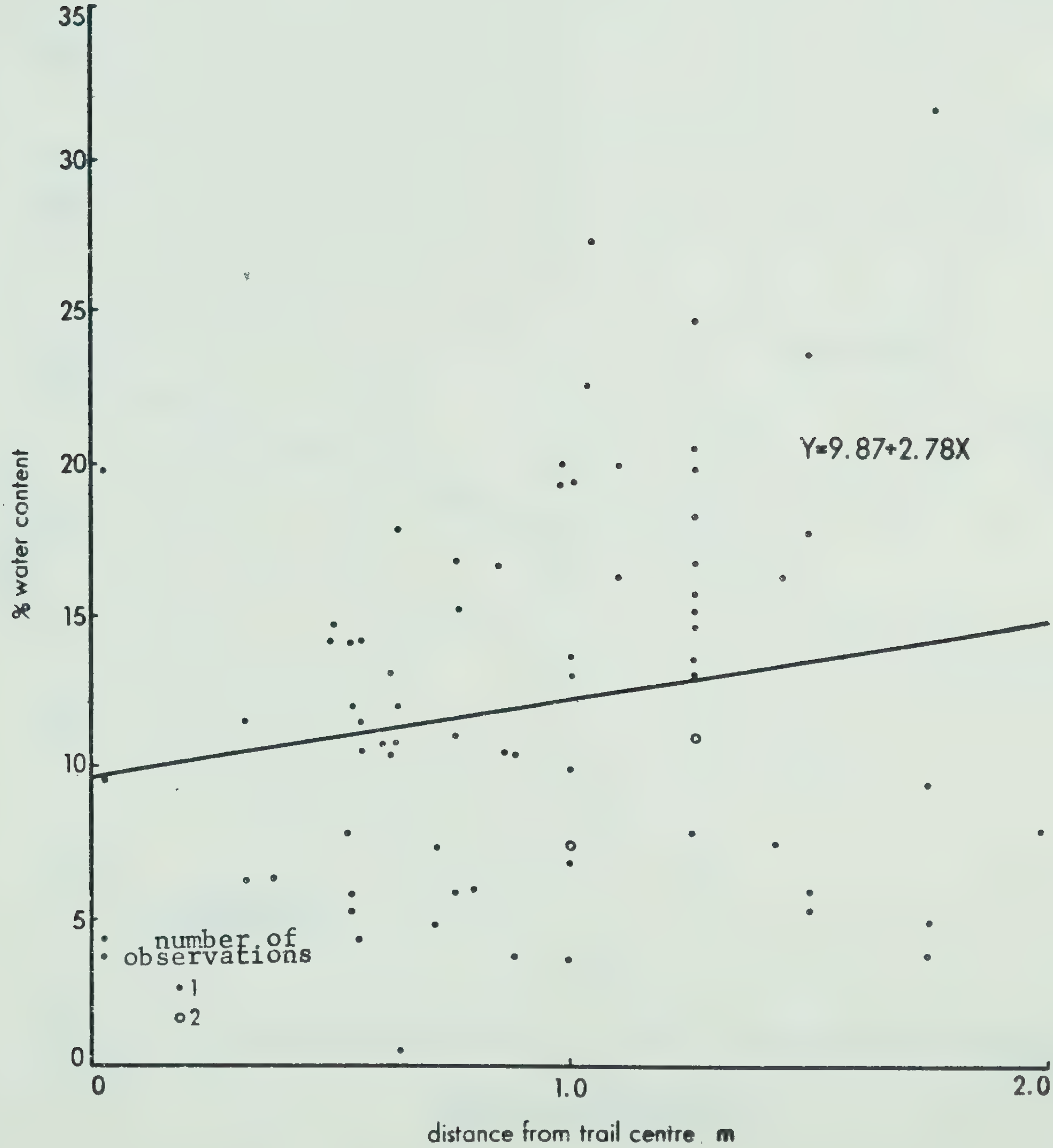


Figure 5.13

Regression of bulk density on distance from the trail centre

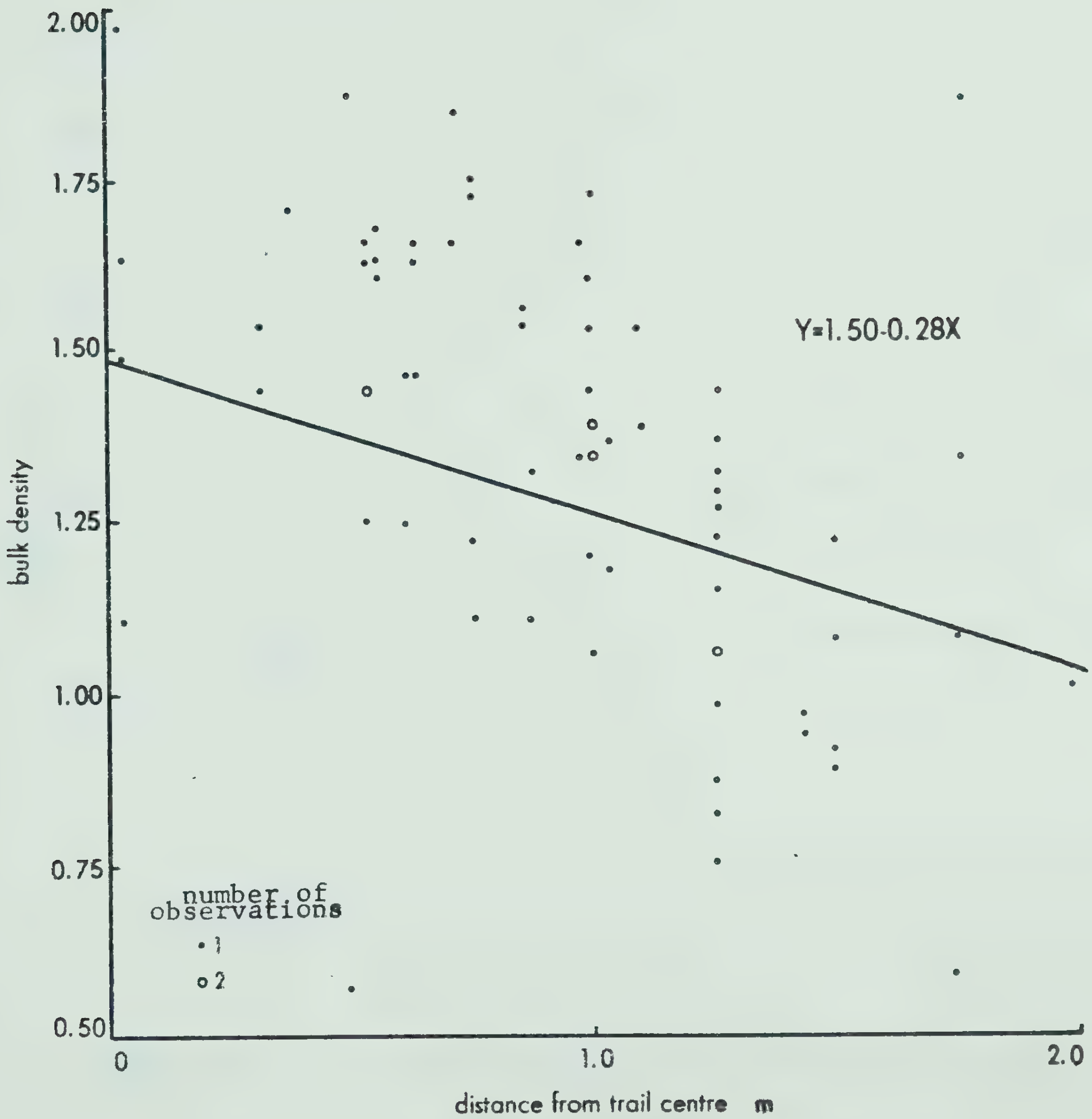


Figure 5.14

Regression of air-filled pore space
on distance from the trail centre

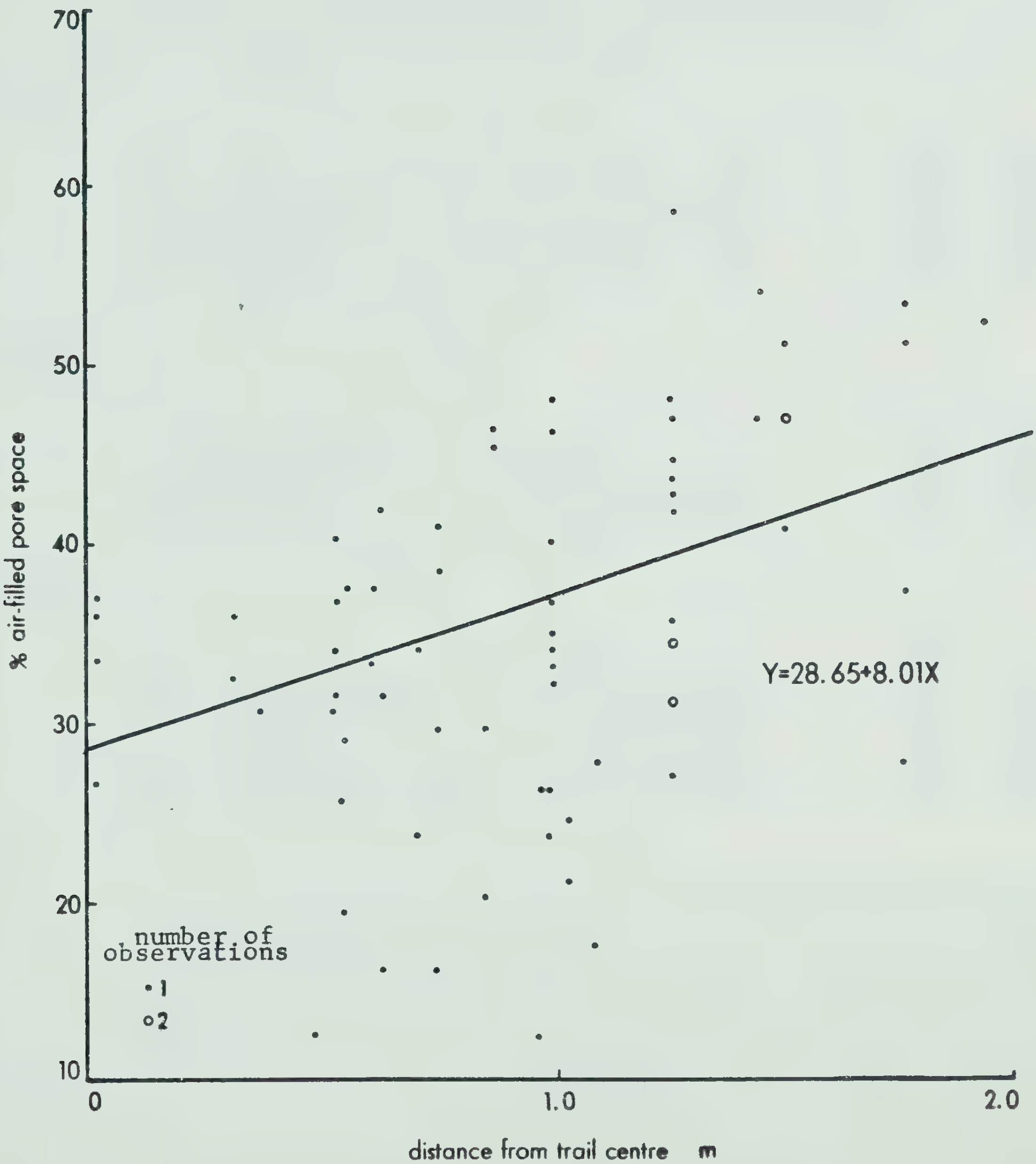


TABLE 5.18 - REGRESSION EQUATIONS

	Dependent Variable	Equation (Y=A+BX)	Significance Level
Total Samples			
	pH	Y = 6.59 - 0.17X	0.005 (98)
	percentage carbon	Y = 1.87 + 1.41X	0.005 (98)
	water content	Y = 9.87 + 2.78X	0.025 (71)
	bulk density	Y = 1.50 - 0.28X	0.005 (71)
	air filled pore space	Y = 28.65 + 8.01X	0.005 (71)
North Side			
	pH	-	Not Significant (58)
	percentage carbon	Y = 2.06 + 1.58X	0.005 (58)
	water content	Y = 9.13 + 2.56X	0.100 (38)
	bulk density	Y = 1.43 - 0.19X	0.005 (38)
	air filled pore space	Y = 33.72 + 5.85X	0.025 (38)
South Side			
	pH	Y = 6.59 - 0.31X	0.005 (58)
	percentage carbon	Y = 1.91 + 1.05X	0.005 (58)
	water content	Y = 10.61 + 3.04X	0.100 (35)
	bulk density	Y = 1.54 - 0.24X	0.005 (35)
	air filled pore space	Y = 23.32 + 8.46X	0.010 (35)

X is the independent variable, the distance from the centre of the path.

Degrees of freedom are placed in brackets beside the significance levels.

and the slope of the regression line is 0.28; this equation is significant at the 0.005 level (71.d.f.).

The regression equations for the variables discussed above and for samples on the north side and the south side of the trail are presented in Table 5.18. This shows that there are differences on the north and south sides of the trail, but as the sample size is reduced, the significance of the relationships decreases. For example, the regression of pH on distance on the north side of the trail is not significant, but for the south side there is a negative regression significant at the 0.005 level (58 d.f.). Bulk density decreases with increasing distance on both north and south sides of the trail. Percentage carbon, water content and air-filled pore space are directly related to distance, although the regression equation for water content is significant only at a 0.100 level and the relationship is therefore weak.

5.4 Plant-Soil Relationships

The preceding sections of this chapter have detailed the evidence on which the following conclusions are based:

i. There are differences between the soil properties associated with a trail and those of the undisturbed adjacent area. From the trail centre and through the edge zone there is a negative linear relationship between distance and bulk density, and a positive relationship between distance and organic matter, moisture content, and air-filled pore space. Soil acidity is more variable than the above characteristics, but there is a general trend for acidity to be reduced towards the centre of the path. These departures from the conditions which would normally be encountered within the undisturbed area are expected to affect the nutrient status of the soil.

ii. There are floristic differences between the trail and its surroundings. In all transects examined, bare or nearly bare ground was found in the centre of the trail. Very few species grew in this zone, although their distribution was such that they might be locally frequent. Although they were not sufficiently numerous to be recorded by the transect analysis, they will nevertheless be discussed in this section. A zone of edge species was recognised at the edge of the trail, its width being partially determined by the width of the path. Moving away from the trail, after the species in this zone had reached their peak cover value, the indigenous woodland species began to gain in importance in the total cover.

It cannot be disputed that trampling has an adverse effect on plant growth and survival by causing physical damage to the plant. Vegetation growing on and beside the trail is therefore subject to physical damage in addition to the effects of the altered soil status, and it is hardly surprising that changes in species cover occur. What is not clear however, is whether the species found in disturbed habitats are there because of specific adaptations to withstand the pressures, or whether they are present because of the reduction in inter-specific competition for resources, caused by the inability of some species to tolerate the environmental conditions. Characteristics of the species found in the trodden path zones must therefore be examined.

As indicated previously, the six most abundant edge species were three grasses, *Poa interior*, *Bromus inermis*, and *Phleum pratense*, and three herbs, *Taraxacum officinale*, *Trifolium repens*, and *Plantago major*. Of these six species only two, *Poa interior* and *Trifolium repens*, are natives, and all are perennials.

The grasses possess deep rooting systems; those of *Bromus inermis* and *Phleum pratense* may extend over one and one-half metres in depth

(Campbell et al., 1966), which would be valuable in tapping the deeper soil layers when the surface soil becomes too dry. *Bromus inermis* has creeping rhizomes and the perennating buds are therefore protected from direct damage by trampling.

Taraxacum officinale and *Plantago major* are rosette plants with a hemicryptophytic life form, the perennating buds being at ground level. *Poa major* in particular has a robust leaf with a tough main rib. *Trifolium repens*, the third herb, possesses prostrate creeping stems which are able to root at the nodes.

Most of the species associated with the edge of the trail therefore have one or more characteristics which allow them to survive in this environment, such as deep rooting systems and perennating buds at or below ground level.

Species that grow on the path encounter even heavier trampling pressures in addition to the greater departure from the normal soil status. An appreciable microclimatic gradient may be experienced across the path, as soil temperature and air temperature over the bare ground will be higher and an increased evaporation rate will undoubtedly be found. The albedo (proportion of short-wave radiation reflected) of bare soil is lower than that of vegetation. Furthermore, the soil surface is protected in a woodland from temperature extremes by a shrub or herb layer.

The two main species that appear to survive on the path despite the adverse conditions are introduced annual herbs, *Matricaria matricarioides* and *Polygonum aviculare*. *Polygonum aviculare* adopts a much-branched prostrate mat form with the buds protected in leaf axils. *Matricaria matricarioides* is an erect plant; observations along the trail indicated that plants growing at the edge with other species tended to be fewer

in number, taller, and produced less flower heads. On one 20 m section of the trail, eight plants with an average height of 10.4 cm and bearing on average 1.6 flower heads were observed growing at the shady edge of the path. On the sunny exposed part of the path by contrast, 26 plants were found with an average height of 4.9 cm and 4.3 flower heads. While these observed differences are probably due to a phenotypic response to the environment, it would be interesting to determine if any of these differences are genotypic in origin, particularly as the smaller plants are better adapted for survival. They are more numerous and produce on average nearly three times as many flower heads (and it is assumed a greater number of viable seeds) than the larger plants growing at the side of the path.

The question of adaptation to, or tolerance of, this inhospitable environment may be likened to that of the tolerance to heavy metals developed in some plant populations in mining and industrial areas. Bradshaw et al. (1965) pointed out that although many habitats are as extreme in pH or salinity as those created by man, such natural habitats are normally vegetated. According to Darwinian concepts, natural selection preserves the most divergent offspring of a species so that vacant niches are colonised. The time scale of evolution, however, must be measured in millennia, while adaptations have been observed to occur within decades (for example, industrial melanism in moths (Kettlewell, 1958) and zinc tolerance in grasses adjacent to a galvanised fence (Snaydon, cited in Bradshaw et al., 1965)). This is evidently not a product of evolution within the species, but a characteristic acquired at the population level.

Bradshaw (1960) found that by crossing the few individuals tolerant to copper in a normal population of *Agrostis tenuis*, full tolerance could

be established in about five generations. The development of an edaphic ecotype was found to create sharp boundaries between the tolerant and non-tolerant populations. Individuals from tolerant populations were at a competitive disadvantage in normal populations. Using game theory, the development of populations, in terms of gene flow and natural selection, was simulated for a number of populations through which ran an ecological boundary. A marked distinction arose between the two populations on either side of the boundary, and equilibrium was reached in about ten generations.

The various strategies which may be adopted by a species or population in the "evolution game" are discussed by Waddington (1965). He emphasised that although formal theories of quantitative and population genetics have been developed over the last two or three decades, there is still very little known about how a species or population meets an evolutionary challenge. At the present time little more than speculation about the influence or mechanism of altering the genetic constitution of colonising species can be attempted.

There is no evidence that polyploid weed species are especially favoured for the colonisation of disturbed areas, since the same proportion of polyploidy was observed in the general flora of an area (Mulligan, 1960). There is, however, some indication that polyploid weeds are better adapted than diploid weeds to some specialised habitats (Mulligan, 1965). A comparison of weedy and non-weedy species of the genus *Chenopodium* indicated that "weediness" may be positively correlated with the amount of phenotypic "plasticity" (Cumming, 1959). Phenotypic plasticity implies a flexibility in the species to adapt its morphology to current environmental conditions; this may be the explanation of the differences observed in *Matricaria matricarioides* on trails in the

study area. Weedy colonisers are also favoured by the ability of a high proportion of the seed population to germinate, achieve a high growth rate, flower, and set seed under a wide range of environmental conditions (Cumming, 1959).

5.5 Summary

The results of this study show that the passage of a path through an area has a marked effect on the soils and vegetation.

Soil moisture, percentage organic carbon, acidity, and air-filled pore space were all reduced on the trail, and increased linearly away from the centre. The soils data are summarised in Table 5.19 and 5.20 for trails A and C respectively. The effect of the altered soil conditions on the availability of soil phosphate and other macro-nutrients was considered, as were the possible consequences of soil moisture reduction and changes in the composition of the soil atmosphere.

Bulk density, which is an indicator of the degree of compaction, increased on the trail. The effects of mechanical impedance to root growth were discussed and special consideration was given to the effects on germination of seeds and subsequent seedling establishment.

The vegetation of the trail was fairly uniform despite the variability of the surrounding vegetation. It appears that a major characteristic of a path is its maintenance of floristic uniformity within zones along its length.

Only two main species were found on the predominantly bare ground of the path, while six major species occupied the edge of the trail where soil conditions and trampling pressures were less inimical to growth and survival.

The possibility of tolerant populations or edaphic ecotypes developing on the trail was considered. It is notable that the two

TABLE 5.19 - TRAIL A: SUMMARY OF SOILS DATA

	Zone	pH	%C	Db	Pw	Pv	St	Sa
Arithmetic Means	N	6.5	3.7	1.15	12.2	13.4	56.5	43.1
	N/2	6.6	3.4	1.33	11.0	13.8	49.8	36.0
	C	6.6	2.2	1.44	9.5	12.2	45.5	33.2
	S/2	6.4	2.6	1.41	12.7	18.0	46.6	28.6
	S	6.2	3.1	1.21	15.0	17.1	54.4	37.3
Range	N	6.2-6.9	1.2-9.3	0.81-1.70	4.7-24.0	6.4-23.8	35.8-69.4	27.8-60.2
	N/2	6.3-6.8	1.3-6.3	0.65-1.65	3.6-27.7	4.6-31.8	40.4-75.5	24.8-66.0
	C	6.0-6.9	0.6-4.9	1.10-1.78	3.8-20.2	6.3-22.2	32.8-58.5	26.1-37.1
	S/2	5.7-6.8	1.3-5.9	0.98-1.69	0.4-22.9	0.5-30.9	36.2-63.0	11.4-55.9
	S	5.6-6.5	1.1-7.7	0.67-1.59	3.9-32.1	4.2-26.3	40.0-74.7	15.2-55.0
Variance	N	0.04	4.61	0.047	30.20	27.47	67.06	71.11
	N/2	0.03	2.68	0.054	39.99	49.25	76.74	89.91
	C	0.06	1.52	0.058	43.80	41.87	84.14	18.69
	S/2	0.08	1.28	0.031	31.81	73.32	43.52	156.88
	S	0.07	2.86	0.055	48.69	36.40	77.35	117.81
Standard Deviation	N	0.20	2.15	0.22	5.49	5.24	8.19	8.43
	N/2	0.16	1.64	0.23	6.32	7.02	8.76	9.48
	C	0.25	1.23	0.24	6.62	6.47	9.17	4.32
	S/2	0.29	1.13	0.18	5.64	8.56	6.60	12.52
	S	0.27	1.69	0.23	6.98	6.03	8.79	10.85

Trail A

%C is percentage organic carbon on an air-dry basis
Db is bulk density in gm/cc
Pw is water content on a dry weight basis
Pv is water content on a volume basis
St is total porosity
Sa is air-filled pore space

TABLE 5.20 - TRAIL C: SUMMARY OF SOILS DATA

	Trail C						
	Zone	pH	Db	Pw	Pv	St	Sa
Arithmetic Means	W	7.0	0.97	17.1	15.2	63.5	48.3
	W/2	7.2	1.30	9.1	11.5	51.0	39.5
	C	7.4	1.52	6.9	10.2	42.5	32.3
	E/2	7.1	1.14	11.0	11.0	57.1	46.1
	E	6.9	0.89	18.5	15.0	66.5	51.5
Range	W	6.0-7.6	0.60-1.30	7.3-25.3	9.4-20.1	50.9-77.4	41.5-62.2
	W/2	5.8-7.9	1.03-1.47	5.9-11.6	8.7-14.1	44.5-61.1	35.9-49.2
	C	6.0-8.1	1.29-1.64	3.4-11.8	5.7-15.2	38.1-51.3	26.7-36.1
	E/2	5.7-7.8	0.73-1.33	4.7-25.2	5.8-18.4	49.8-72.4	37.8-54.0
	E	5.9-7.5	0.60-1.10	11.0-28.4	11.7-17.1	58.5-77.4	43.0-62.4
Variance	W	0.33	0.051	42.50	13.74	73.68	52.84
	W/2	0.52	0.022	4.16	3.18	30.82	24.61
	C	0.60	0.016	8.93	13.03	23.26	9.73
	E/2	0.65	0.043	55.25	20.99	62.44	31.33
	E	0.46	0.053	43.32	3.79	76.26	68.18
Standard Deviation	W	0.58	0.22	6.52	3.71	8.58	7.27
	W/2	0.72	0.15	2.04	1.78	5.55	4.96
	C	0.77	0.13	2.99	3.61	4.82	3.12
	E/2	0.80	0.21	7.43	4.58	7.90	5.60
	E	0.68	0.23	6.58	1.95	8.73	8.26

Db is bulk density in gm/cc
Pw is water content on a dry weight basis
Pv is water content on a volume basis
St is total porosity
Sa is air-filled pore space

species found on the trail were annuals (therophytes), which suggests that a large gene pool and an annual replacement of individuals confers a more rapid adjustment to the prevailing conditions. The edge species were found to possess characteristics that gave them a certain amount of resistance to trampling and hence a competitive advantage over the typical woodland species.

These, and other considerations, are incorporated into a model of trail development which is discussed in the following chapter.

CHAPTER VI

CONCLUSIONS

Trail status measured during this study in the Cypress Hills indicates certain general principles; these are discussed below and used to establish a model of trail development or evolution. Also considered are some aspects of the method used to determine trail status and suggestions are made for its improvement. Finally there is a discussion of the most profitable direction that future trail studies might take.

6.1. General Principles of Trail Status

6.1.1 Characteristics of Trail Status

The results indicated the following characteristics of the uppermost layer of mineral soil:

i. Bulk density, which is a measure of soil compaction, decreases linearly with distance from the centre of the trail while there is a concomitant increase in total porosity and air-filled pore space.

ii. Moisture content increases linearly with distance from the centre of the trail.

iii. The organic carbon content increases linearly with distance from the trail centre.

iv. Acidity increases linearly with distance from the trail centre.

v. The highest roughness factors, which are a measure of the lowering of the trail surface relative to its surrounds, are found on steep west-facing slopes. The ability of steep slopes to produce high roughness factors is dependent upon their aspect, which controls the nature

of the vegetation, and exposure to agents of erosion such as rainfall and snowmelt runoff.

vi. Few species are able to tolerate the rigorous conditions found at the trail centre; the two major species are annuals. The six most important species found at the trail edge are perennials which exhibit one or more characteristics that contribute to minimising the adverse effects of trampling. These species achieve a peak value for cover and then decline in abundance. A few typical woodland species were also found at the trail edge, and these increase their cover with distance away from the trail. In addition there is an increase in the number of typical woodland species found with distance away from the trail edge.

The linear relationship between distance from the trail centre and bulk density, moisture content, organic carbon content and soil acidity is not expected to be maintained when distance from the trail is sufficiently increased. When the disturbing effects of the trail are minimised, fluctuations in the soil variables will reflect the natural heterogeneity of such systems.

From the specific conclusions and general observations, a model of the development of trail status is proposed.

6.1.2. Model of Trail Status Development

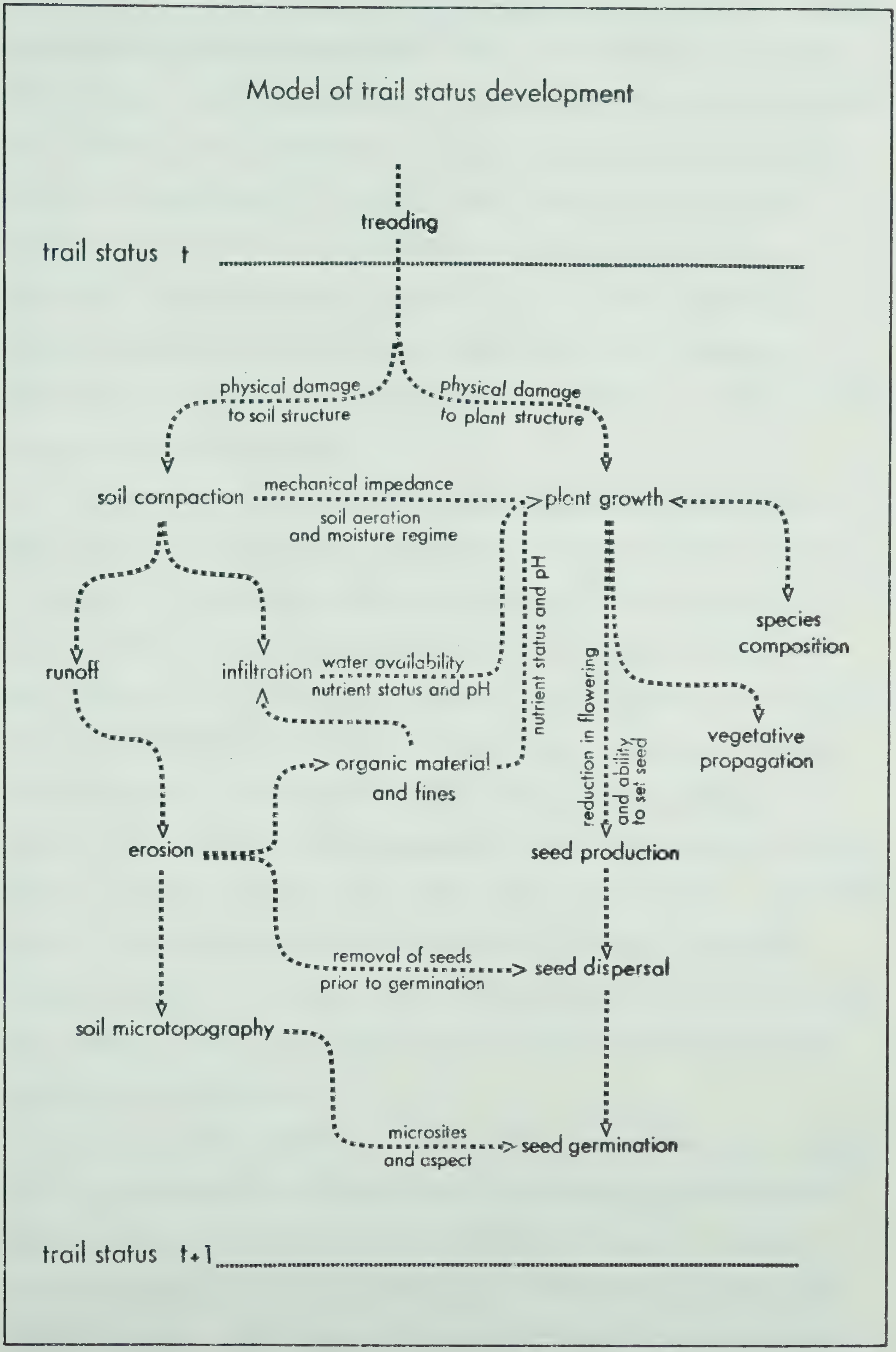
It is important to realise that trail status as developed here is a description of the physical and biological attributes of a trail at a point in time, and implies no causal relationships. It is a dynamic character that changes over time regardless of whether or not the trail is used. The degree of use or non-use merely determines the direction that the changes in time will take. It is not possible therefore to indicate definitive causal relationships on the basis of

observations during only one field season. However, it is correct to state that the current trail status has resulted from two causes: trail use by man and animals, and biotic and abiotic interactions which proceed independently from trail use. As trail status is a dynamic quantity and continuously changing, it is simpler to consider the changes occurring between distinct points separated in time rather than the continuous change.

The principles governing changes in trail status that might occur are therefore discussed with the aid of a model (Figure 6.1) on a seasonal basis. The trail status is first considered after snowmelt in the spring when the growing season begins. The amount of plant growth associated with the trail will be governed by the trail status in terms of impedance to root growth, soil moisture and atmospheric conditions, and soil nutrient status. The availability of seed will affect the potential establishment of new individuals, and weather conditions will also be important. The latter are not included however as they are variable from year to year and influence all plant growth.

The introduction of treading pressures into the system causes physical damage to the vegetation. Where the soil is not cushioned by a plant cover it receives direct trampling pressure, and the amount of compaction this causes is related to its status at that time. Conditions most conducive to compaction are a high moisture content (with maximum compaction at a point midway between field capacity and wilting point), low initial density, and low organic content (Lull, 1959). The increase in compaction has a direct effect on plant growth by causing mechanical impedance to root growth, and indirectly affects it through soil aeration and the moisture regime. Increasing compaction results in

Figure 6.1


Model of trail status development
treading
trail status t
physical damage
to soil structure
physical damage
to plant structure
soil compaction
mechanical impedance
soil aeration
and moisture regime
plant growth
species
composition
nutrient status and pH
reduction in flowering
and ability
to set seed
runoff
infiltration
water availability
nutrient status and pH
vegetative
propagation
organic material
and fines
erosion
seed production
removal of seeds
prior to germination
seed dispersal
soil microtopography
microsites
and aspect
seed germination
trail status t+1

an increase in runoff compared to infiltration, and the latter affects plant growth through the moisture content. Increasing runoff on the path increases erosion and losses of organic matter and fine textured soil material. This affects the nutrient status by reduction of the cation exchange capacity (potential sites that may be occupied by exchange cations). It is possible however that the percentage base saturation (the proportion of potential sites actually occupied by exchange cations) may increase as, concomitant with an increase in runoff there is a decrease in infiltration, and hence a smaller potential loss of cations by leaching.

The negative effects on plant growth may affect its ability to reproduce, both by vegetative propagation and by production of seed. A decrease in flowering is observed in plants at the edges of paths and therefore it is surmised that there will also be a decrease in seed production. Although seed dispersal may be adequate on the path, it is suggested that the increase in runoff will remove a proportion of these seeds. This is particularly likely to happen during heavy storms in the autumn, and during snowmelt runoff in the spring; further storms in late spring may remove seeds prior to germination. Germination is also affected by the path roughness which influences the micro-climatic gradients across the trail in addition to heterogeneity of the soil surface. This will be important to seeds having very specific germination requirements.

The composition of the plant cover will be determined by the ability of different species to survive under the conditions on and beside the path as well as interspecific competition for resources. The most successful species occupy the path edge at the expense of less well-adapted species. This study indicated that "weedy" species were more

successful than typical woodland species, so that the edge of the path displayed a characteristic flora.

The model trail therefore becomes less favourable to plant growth over the period described. As plant cover is decreased and more bare soil is exposed, the situation deteriorates. The cushioning effect of vegetation is lost, the trampling force is directed onto the soil surface, and hence compaction occurs more readily. There is also a concurrent increase in compaction due to the impact of rainfall which is now received directly by the soil surface. The increase in compaction and lack of vegetation enhances the erosion potential, and this combination of factors is thought to account for the deeply incised form of the path on steep slopes, especially those facing the direction from which precipitation falls. Aspect of the slope is also important in that it affects the general nature of the vegetation cover. The effect of path microtopography has already been mentioned as influencing germination; seedling establishment is subject to the same controls exercised by soil status as were described for plant growth.

At the end of the period described in the model, trail status has acquired a different set of attributes from those it possessed originally. Several aspects of the model are worthy of comment. The trampling pressure applied during the next period is therefore acting on a different trail status and hence we cannot say that even with identical pressure the effects will be the same. As a site becomes increasingly degraded less pressure will be required to maintain it, as the element of self-perpetuation increases. In restoring recreation areas such as trails or campsites by revegetation, difficulties may be encountered as the model shows that weedy plants under these conditions are often more successful than indigenous species.

The possible use of trail status (as an expression of concentrated pressure) to the prediction of heavy use over a large area was suggested (Chapter 1.6). On the basis of this study, it is proposed that this is indeed valid although it cannot be applied on a quantitative basis without a user-study to determined the exact pressures exerted. It may nevertheless provide an indication of ground cover reaction to trampling, and of plants that might replace the indigenous species. This is of particular importance on a campsite, for seeds may be transported long distances by vehicles and on footwear and clothing so that a supply of non-native seeds is virtually inevitable.

The model has been presented in a general form, but the emphasis is on the interaction of all parts in the system. This holistic approach has been expressed by Watt (1966) as "a principal attribute of the system is that we can only understand it by viewing it as a whole".

6.2 Critique of Methods

Many of the more detailed points have been previously discussed in conjunction with the results (Chapter V), and this section is concerned with the overall success of the sampling and analysis. Any changes in methods must still fulfill the requirements of causing minimum disturbance on the site.

The period of time over which the samples are taken could be reduced. This would make comparisons as valid along the trail as across the trail, but would entail a team of field workers if a large number of transects were to be sampled. The period of time for which samples have to be kept both in the field and in the laboratory must also be reduced to the minimum possible. Measurement of pH immediately after sampling is preferable to storing the samples when the change that they will undergo is unknown in both magnitude and direction.

The point-quadrat method of determining species cover is most suited to low-growing vegetation. It was appropriate to this study as the vegetation alongside the path was easily sampled and the transect was discontinued when the vegetation regained its normal cover characteristics, including a shrub layer which could not have been sampled by this method.

The determination of cation exchange capacity and percentage base saturation would prove a useful addition to the organic carbon results, and might confirm the suggested hypothesis of the effects on soil nutrient status. In this respect, soil nitrogen, sodium, potassium, calcium, magnesium and phosphate could be included to give a more complete picture.

Infiltration and runoff rates would enable an estimate of erosion to be made and related to trail status.

The study showed that a fairly clear parallel zonation exists along the trail; the sampling approach could therefore be changed so that it emphasises zonal characteristics, by sampling in such zones as path centre, midway between the centre and edge, path edge, peak of edge species cover, and the point where edge species cover and typical species cover are equal.

6.3 Future Investigations

6.3.1 Systems Approach

One possible course for future investigations is an analysis of trail and recreation site status development based on a systems approach. The model already presented gives a simple outline of the components of the system. Because the system was not studied over a period of time, values cannot be assigned to rates of status change; the study has established the nature of some of the changes, thereby providing an

orientation for future work. If, however, the model is used as a basis for further study, trail status at time t+1 after the period described can then be expressed as a function of trail status at time t. The time element is therefore treated by the use of recurrence formulae. As the variables change in direction as well as quantity, vector analysis is appropriate; differential equations, with or without a time-lag incorporated, can be used to describe the system.

If x_t and v_t are vectors describing trail status, the change of status is given as:

$$\frac{dx}{dt}1 = f(x_{t-1}) + g(v_{t-1}) \quad \text{... with no time lag}$$

$$\frac{dx}{dt}1 = f_1(x_{t-1}) + f_2(x_{t-2}) + g_1(v_{t-1}) + g_2(v_{t-2}) \quad \text{...with a time lag}$$

f is a function of x, g is a function of v.

The above equations are given by Watt (1966) as appropriate to apply to a system with many interrelated variables that evolve historically, and are hence applicable to the recreation situation. The use of continuous system simulator programmes is recommended by Brennan et al. (1970) to simplify the working of such models in which, for example, the coefficients of the differential equations vary with time. Other approaches have been applied to simulation studies (Patil et al., 1971); such studies are accepted as contributing to both the descriptive and predictive aspects of ecological model building.

6.3.2 Recording Visitor Use

When the development of trail status is better understood, and the major contributory components in the deterioration of a site evaluated, the means to improve the management of such sites will be available.

One of the first priorities is to relate the status of an area to

the use that it receives, and at the present time no study has been able to accomplish this with any degree of certainty. This suggests that the most valuable work in the future will be based on monitoring the development of trail status on a new recreation site. This will provide the opportunity to conduct a thorough survey prior to any organised recreation use, and then to monitor the number of visitors, their behavioral patterns, and the concomitant environmental changes.

It has already been mentioned that use could not be related to status on a transect basis (Chapter 1.6) unless the location of users on a transect, as well as their numbers, was recorded. The recording of visitor behaviour must be done in such a way that the behaviour is not influenced. Automatic people counters have been used in recent years (Hammond, 1967; Goldsmith et al., 1970) to estimate the numbers of people at a point. Further development based on the photoflux principle has improved the efficiency and reduced the size of a counter (Bayfield and Pickrell, 1971). The photocells respond to the change in light flux impinging on them produced by a passing object, and cause a change in electrical current which is used to trigger a digital counter. However, to record the location as well as the number of people passing, the photoflux counter could be adapted to trigger a hidden camera. This would combine the best of both photoelectric and manual photographic grid techniques. The digital counter could also be checked to determine the degree of error in the estimates, caused by such occurences as double counts of single events and vice versa. A record of the time of day that the photograph was taken, such as is found on aerial photographs, would establish the temporal pattern of use.

The cost of setting up such a system would mainly lie with the camera equipment. However, the amount of information obtained would

probably justify the initial expense especially as the method would not influence visitor behaviour and would reduce field personnel.

Data could be removed from the film by projecting the negative onto a grid and coding the information directly. After sufficient sampling had been carried out to establish the pattern of visitor use, the photoflux equipment alone could be used, and the camera moved to another site. A complete photoflux counter may be purchased for about £20 ($ 50) (Bayfield and Pickrell, 1971), or assembled from components at even less cost. This device has great potential as a useful and inexpensive tool in monitoring visitor use patterns.

6.3.3 Recording Habitat Data

A similar simple technique to record the changes occurring in vegetation and soils with use is required. The methods used in this study were directed to documenting the trail status. In the future we will need a rapid means of assessing the status of recreation sites, and coding this information along with user-data. A means of recording this status may be developed along the lines of the Geogram chart, which was devised for a world inventory of all types of surface features contributing to the environment of man and the habitats of animals and plants (Nicholson, 1971). The chart consists of an open framework on which the habitat features are plotted for a particular region. The framework may also be used to plot distribution and frequency of species according to habitat type. By using a similar system for recreation sites and coding the data, similarities between locations could be established and related to other variables (such as climatic conditions) and a check could be kept on the change in status over time.

Many of these ideas will be easier to put into action when a more solid base of research has been established, and when there is a better

understanding of the processes governing the status of recreation sites. It is anticipated that studies comparable to the present one, and with the emphasis on a systems approach, will contribute to this understanding.

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APPENDIX A

LIST OF BOTANICAL AND COMMON NAMES OF PLANT SPECIES

This list of vascular plants is based on Moss (1959) and adopts the same system of listing the genus and species alphabetically within the family, except for the grasses, which are listed alphabetically within each tribe. Additional information was obtained from Hubbard (1954).

PINACEAE

Picea glauca (Moench) Voss	white spruce
Pinus contorta Loudon var. *latifolia* Engelm.	lodgepole pine

GRAMINEAE

<u>Hordeae</u>

Agropyron subsecundum (Link) Hitchc.	bearded wheat grass
Hordeum jubatum L.	foxtail barley
Lolium perenne L.	perennial rye-grass

<u>Agrostideae</u>

Agrostis scabra Willd.	hair grass
Agrostis tenuis Sibth.	common bent
Phleum pratense L.	timothy

<u>Festuceae</u>

Bromus anomalus Rupr.	nodding brome
Bromus inermis Leyss.	awnless brome
Cynosurus cristatus L.	crested dog's-tail
Festuca idahoensis Elmer	bluebunch fescue
Festuca ovina L.	sheep fescue
Festuca rubra L.	red fescue
Festuca scabrella Torr.	rough fescue
Poa annua L.	annual bluegrass
Poa interior Rydb.	
Poa palustris L.	fowl bluegrass
Poa pratensis L.	Kentucky bluegrass

CYPERACEAE

Carex sprengelii Dewey	sedge

JUNCACEAE

Juncus tenuis Willd.	rush

LILIACEAE

Disporum trachycarpum (S. Wats.) B. & H.	fairy bells
Smilacina stellata (l.) Desf.	star flowered solomon's-seal

SALICACEAE

Populus balsamifera L.	balsam poplar
Populus tremuloides Michx.	trembling aspen

POLYGONACEAE

Polygonum aviculare L.	common knotweed

CARYOPHYLLACEAE

Stellaria longifolia Muhl.	long leaved chickweed

RANUNCULACEAE

Actaea rubra (Ait.) Willd.	baneberry
Thalictrum venulosum Trel.	veiny meadow rue

CRUCIFERAE

Capsella bursa-pastoris (L.) Medic.	shepherd's purse

ROSACEAE

Amelanchier alnifolia Nutt.	saskatoon-berry
Fragaria glauca (S. Wats.) Rydb.	wild strawberry
Geum allepicum Jacq.	yellow avens
Rosa acicularis Lindl.	prickly rose
Rosa woodsii Lindl.	common wild rose
Rubus strigosus Michx.	wild red raspberry
Spiraea lucida Dougl.	white meadowsweet

LEGUMINOSAE

Hedysarum alpinum L.	hedysarum
Lathyrus ochroleucus Hook.	vetchling
Melilotus alba Desr.	white sweet clover
Thermopsis rhombifolia (Nutt.) Richards	golden bean
Trifolium repens L.	white clover
Vicia americana Muhl.	wild vetch

GERANIACEAE

Geranium richardsonii Fisch. & Trautv.	white geranium

VIOLACEAE

Viola rugulosa Greene	western Canada violet

UMBELLIFERAE

Heracleum lanatum Michx.	cow parsnip
Osmorhiza chilensis Hook. & Arn.	sweet cicely

MONOTROPACEAE

Pterospora andromeda Nutt.	pine-drops

SCROPHULARIACEAE

Castilleja miniata Dougl.	common paint brush

PLANTAGINACEAE

Plantago major L.	common plantain

RUBIACEAE

Galium boreale L.	northern bedstraw

CAPRIFOLIACEAE

Lonicera dioica L. var. *glaucescens* (Rydb.) Butters	twining honeysuckle
Symphoricarpos albus (L.) Blake	snowberry

CAMPANULACEAE

Campanula rotundifolia L.	harebell

COMPOSITAE

Achillea millifolium L.	common yarrow
Agoseris glauca (Pursh.) Raf.	false dandelion
Antennaria spp.	pussy-toes
Artemisia frigida Willd.	pasture sagewort
Artemisia ludoviciana Nutt.	prairie sagewort
Aster ciliolatus Lindl.	Lindley's aster
Aster laevis L. var. *geyeri* A. Grey	smooth aster
Erigeron spp.	fleabanes
Gaillardia aristata Pursh.	gaillardia
Hieracium spp.	hawkweeds
Matricaria matricarioides (Less.) Porter	pineapple weed
Solidago decumbens Greene	goldenrod
Solidago gigantea Ait.	goldenrod
Taraxacum officinale Weber	common dandelion

APPENDIX B

DISCUSSION OF NEGATIVE ROUGHNESS FACTORS AND POSSIBLE SOURCES OF ERROR IN CALCULATING THE ROUGHNESS FACTOR

Three negative roughness factors are shown in Table 5.14. Two of these are very small values; the third is large and thought to be occasioned by the misapplication of the criteria used to locate the path edge.

If the path surface follows closely the line on which the slope factor is calculated, but crosses that line on one or more occasions, then the total variance may be reduced to a value lower than the slope factor. The negative values for roughness factor that result therefore indicate that the path surface was in some places higher than the line joining the ends of the microtopography transect. This was confirmed for the transects with low negative roughness factors. This condition is met infrequently in the field as it is usual for the whole of the trodden area to be lowered relative to the path edges.

As this method of characterising trail roughness has not been attempted before, a brief discussion of the possible sources of error is included. Because the roughness factor is obtained by subtraction of the slope factor from the total variance, an error in either of these will affect the final value. These possibilities are outlined below.

i. If the line from which vertical measurements are made is not quite taut, the vertical measurements will be too small. The corrections to bring them to the horizontal are based on a taut line, and any errors caused by sag in the line will therefore be transferred, hence the total variance will be reduced. The slope variance will not be affected as it is calculated independently.

ii. If the slope of the measurement line α is recorded as greater or smaller than is actually the case further errors may occur. If it is too large, the total variance will also be too large, because the horizontal correction factors will be correspondingly increased. However, the width will be calculated as too small, although the difference will be minimal as the cosine of slope angle is used in the calculation.[1] Providing that the difference in height between the two edges of the trail is correct, the width error has negligible effect on the slope factor, as it is compensated for by an increase in slope angle β, for example:

<u>Effect of error in width on slope factor</u>

vert. diff.	width	slope	slope factor
8.75	110	4° 33'	7.45
8.75	100	5°	7.56

There is therefore little effect on slope factor even with width error approaching 10%. This is an extreme example and unlikely to be encountered in the field. Width errors of 1-1.5% are a more realistic estimate.

The vertical difference in the height of the edges would be increased if an overly large correction factor was added to one end (the other end always has a correction factor of zero). This would produce too great a slope factor.

If the measurement line slope α is recorded as too small, by a similar argument to that above the total variance will also be too small. The effect on width is again negligible, although in this case

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1. cos 1° = 0.9998, cos 5° = 0.9962, and cos 10° = 0.9848. Angles rarely exceeded 10°.

it would be increased and the slope angle decreased. However, when the vertical difference is decreased as well a decrease in slope factor will result.

The magnitude of these errors is sufficiently small that the effect on the results is likely to be minimal. This method is therefore a very convenient way to obtain a rapid and accurate estimate of trail roughness, or microtopography.

Relationship between roughness factor and path width

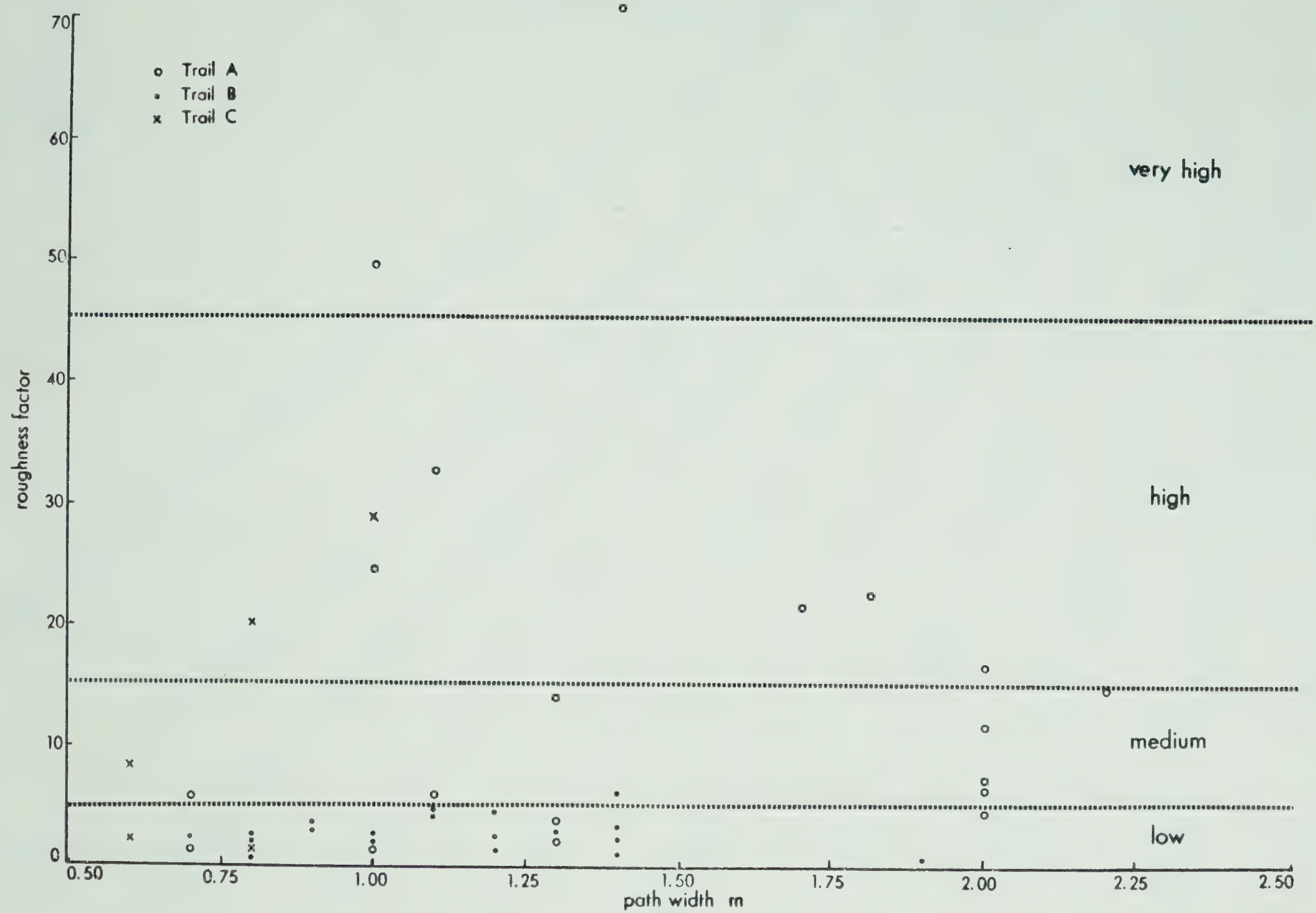
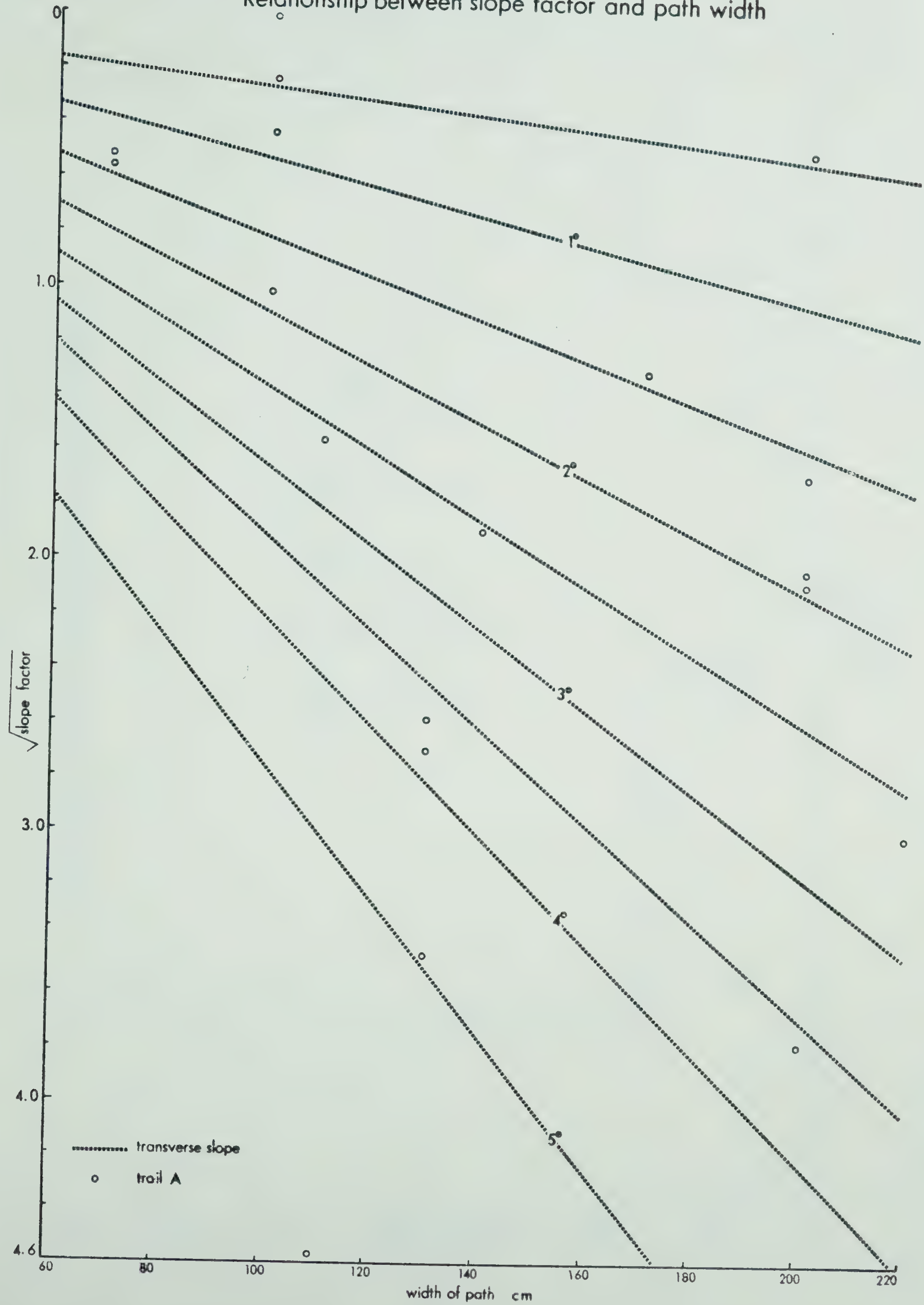


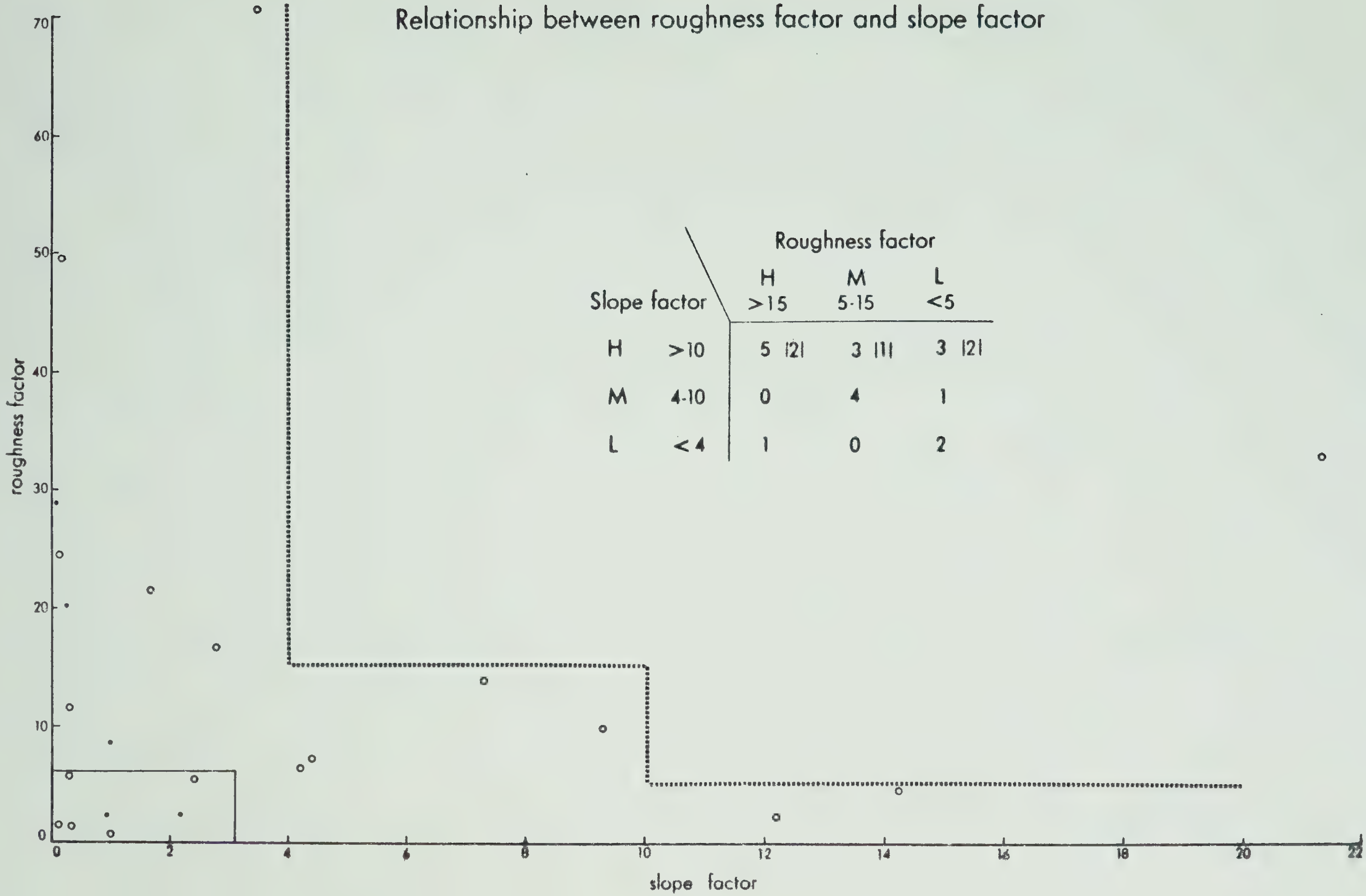
Figure B.1

Figure B.2

Relationship between slope factor and path width



Relationship between roughness factor and slope factor



Slope factor		Roughness factor H >15	M 5-15	L <5
H	>10	5 (2)	3 (1)	3 (2)
M	4-10	0	4	1
L	<4	1	0	2

Figure B.3